VOLUME 18 OCTOBER, 1930 NUMBER 10

PROCEEDINGS
of
The Institute of Radio Engineers

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Institute of Radio Engineers
Forthcoming Meetings

DETROIT SECTION

October 17, 1930

LOS ANGELES SECTION

October 20, 1930

NEW YORK MEETING

Rochelle Salt Crystals in High-Frequency Circuits, by W. G. Cady
Wesleyan University, Middeltown, Conn.

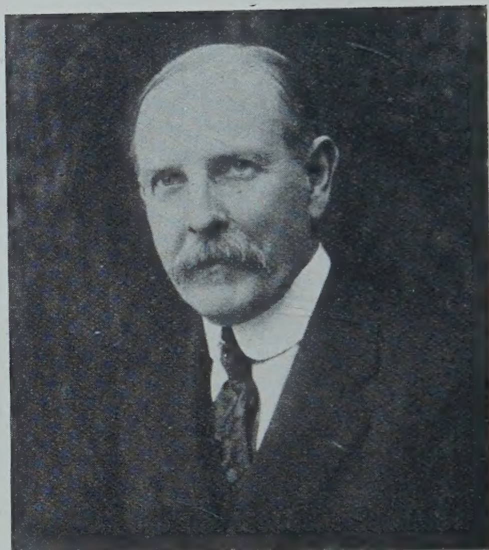
November 5, 1930

PITTSBURGH SECTION

October 20, 1930

SAN FRANCISCO SECTION

October 15, 1930



Arthur E. Kennelly
President of the Institute, 1916

Arthur Edward Kennelly, fifth president of the Institute, was born at Bombay, India, on December 17, 1861.

Professor Kennelly received his early education in England, Scotland, France, and Belgium and in 1876 he joined the staff of the Eastern Telegraph Co. as a submarine cable telegraph operator, rising to be senior ship chief electrician in 1886. From 1886 to 1894 he was principal electrical assistant to Thomas A. Edison, at Orange, N. J., and also acted as a consulting engineer for the General Electric Co. during 1890–1894. With E. J. Houston he formed the firm of Houston and Kennelly, constructional engineers which operated in Philadelphia from 1894 to 1901.

In 1902 he became Professor of Electrical Engineering at Harvard. From 1913 to 1925 he was a member of the faculty of The Massachusetts Institute of Technology, returning to Harvard in 1926 where he is at present.

He was assistant secretary of the Institute of Electrical Engineers (London) in 1878; president of the American Institute of Electrical Engineers, 1898–1900; president, Illuminating Engineers Society, 1911; president, Institute of Radio Engineers, 1916; and vice president of the American Association for the Advancement of Science and the American Academy of Arts and Sciences. He is a member of the mathematical Society and the Physical Society, Honorary Fellow of the Electro-Therapeutic Association, Philosophical Society, American Academy of Arts and Sciences, Pacific Astronomical Society, and the Franklin Institute. He holds honorary memberships in the National Electric Light Association, the New York Electrical Society, Institute of Electrical Engineers (London), and Societe Francaise de Electrique, and is a corporate member of the British Association for the Advancement of Science.

He became secretary of the U. S. National Committee of the International Electrotechnical Commission in 1910, assuming the secretaryship from 1910 to 1922 and receiving the appointment of honorary secretary in 1923.

He has received two awards from the Institute of Electrical Engineers (London), the Longstreth and Potts medals of the Franklin Institute and is a chevalier of the Legion d'Honneur.

Professor Kennelly's two main contributions to technology in electrical engineering are the introduction of complex numbers into engineering from the shelves of pure mathematics in 1893 by introducing the extension of Ohm's law to alternating-current circuits by complex numbers and their vectors, and the application of complex angles and hyperbolic functions to alternating-current circuits, following algebraic suggestions contained in the works of Heaviside, although Heaviside himself did not use the method.

As regards radio, Professor Kennelly was the first to suggest that the ionized conducting layer in the upper atmosphere was responsible for the reduction in attenuation in radio signals at great distances. His name has been coupled with that of Heaviside in this work as both independently reached the same conclusion. The independent writing of these theories occurred within a few months of each other.

Professor Kennelly joined the Institute as an Associate in 1912, transferring to Member in 1913, and to the Fellow grade in 1928.

INSTITUTE NEWS AND RADIO NOTES

Rochester Fall Meeting

A special all-day meeting of the Institute will be held at the Sagamore Hotel in Rochester on Friday, November 21, 1930. A number of speakers will present informal papers on subjects of considerable interest to engineers. As these papers will not be preprinted for the meeting and most of them will probably not appear in the Proceedings, it will be necessary for those interested in the papers to be present.

The opening session will start at 10:00 A.M. at the Sagamore Hotel Roof where the Eastern Great Lakes District Convention was held in November of 1929. Dr. Dellinger will preside at the three technical sessions scheduled and the program is as follows:

Registration—9:00 A.M.

Morning Session—10:00 A.M.

"The 227 Equipotential Cathode Tube" by A. C. Rockwood, Hy-Grade Lamp Works.

"Notes on Circuit Design" by Fulton Cutting, Colonial Radio Corporation.

Luncheon—12:30 P.M.

Afternoon Session—2:00 P.M.

"Some Considerations in Superheterodyne Design" by David Grimes, Radio Corporation of America.

"A New Low-Distortion Radio Amplifier Tube, Type 551" by Stuart Ballantine and H. A. Snow, Boonton Research Corp.

"The Thyratron—What it is and What it Does" by J. C. Warner General Electric Co.

Dinner—6:30 P.M.

Evening Session—8:00 P.M.

"Extending the Radio-Frequency Spectrum" by A. Hoyt Taylor, Naval Research Laboratory.

Rochester is a very convenient place to reach by railroad. Trains leaving New York, Boston, and Chicago arrive in Rochester the following morning in ample time for those traveling to attend the opening session of the meeting. There are a number of trains leaving Rochester for New York, Boston, and Chicago between 10:00 P.M. and midnight so that those attending the meeting can reach the above mentioned cities by Saturday morning. As the meeting is scheduled for one day only, there will be no necessity of the delegates having to stay in Rochester overnight. The actual time away from regular business will, therefore, be only the day during which the meeting is held, and in

view of the number of papers and their significance, the journey should be amply repaid.

No advance registration is required.

1930 Convention

The fifth annual and first international convention of the Institute was held in Toronto, Canada, August 18 to 21, 1930. The convention was attended by five hundred and seventy-five members and guests who were from all sections of the United States and Canada. In addition, members from Austria, England, Germany, France, and Italy were in attendance.

The program of the first three days of the convention was terminated by the annual banquet at which three hundred members and guests were present. The award of the Institute Medal of Honor to Professor P. O. Pedersen of the Royal Technical College at Copenhagen, Denmark, and the Morris Liebmann Memorial Prize to Dr. Albert W. Hull of the Research Laboratory of the General Electric Co. were made during the banquet.

The golf tournament which was held at the St. Andrew's golf course was won by Arthur F. Rose of the American Tel. & Tel. Co. The trophy which is in the form of a silver cup was presented by the Toronto Section and is to be competed for annually. A smaller cup will be retained by the winner each year and the large cup will be in possession of the last winner until it has been won three times by the same player, in which case it will become a permanent award. Presentation of this cup was also made during the banquet which was followed by professional entertainment and dancing by the guests.

The entire last day of the convention was devoted to a trip to Niagara Falls, The Queenston Power Plant, and the Welland Ship Canal.

During the technical sessions, twenty-three papers were presented and a number of committee meetings were held throughout the first three days of the convention.

We acknowledge our appreciation of contributions made by a number of Canadian and U. S. manufacturers and dealers in radio goods and in particular to the Canadian General Electric Company whose name was inadvertently omitted from the list distributed during the convention.

The annual meeting of the Committee on Sections which was attended by representatives of nine of the seventeen Institute Sections was held on August 19. A new Section constitution was approved for recommendation to the Board of Direction. It is hoped that this constitution will be sufficiently broad to allow its adoption by all Sections.

The rebate system now in operation was considered carefully and it

was recommended that this be changed to call for a rebate to each Section of 50c per year for each member residing in the Section territory. In addition, a rebate of $10 will be paid for each meeting of the Section held. It is the belief that this system will more equitably distribute Section funds and permit a number of the smaller Sections to carry on their operation more successfully.

September Meeting of the Board of Direction

A meeting of the Board of Direction was held at 4:30 P.M. on Wednesday, September 3, 1930 at the offices of the Institute, 33 West 39th Street, New York City. The following members were present: R. H. Marriott, acting chairman, Melville Eastham, treasurer, R. A. Heising, J. V. L. Hogan, C. M. Jansky, Jr., A. F. Van Dyck, and H. P. Westman, secretary.

The following were transferred or elected to the higher grades of membership in the Institute. For transfer to the Fellow grade: R. H. Manson and C. W. Horn. For transfer to the Member grade: V. J. Andrew, C. M. Burrill, F. A. Gunther, J. G. Mullen, Gregory Ogolobinsky, E. B. Patterson, A. C. Rockwood, R. L. Schoen, Clayton Shangraw. For election to the Member grade: C. R. Clark, M. M. Das, L. M. Harvey, C. J. Mercer, S. C. Nixdorff.

One hundred and seven Associate members and four Junior members were elected.

Nomination of 1931 Officers and Managers

The Board of Direction of the Institute has nominated the following candidates for offices of the Institute during the coming year:

For President: R. H. Manson, Chief Engineer, Stromberg-Carlson Telephone Manufacturing Co., Rochester, N. Y. Member, Board of Direction, 1927–30. Fellow of the Institute.

For Vice President: C. P. Edwards, Director of Radio, Canadian Marine Department, Ottawa, Ont., Canada. Member, Committee on Standardization. Fellow of the Institute.

For Managers (three year terms)

L. M. Hull, Vice President, Radio Frequency Laboratories, Boonton, N. J. Member, Board of Direction, 1929–30. Chairman, Committee on Broadcasting; Member, Committee on Meetings and Papers. Fellow of the Institute.

A. F. Van Dyck, Radio Corporation of America, New York City. Member of Board of Direction, 1930. Member, Committee on Admissions and Committee on Bibliography. Fellow of the Institute.

Proceedings Binders

Because of the enlarged size of the PROCEEDINGS published during 1929, many of our members find that they are unable to fit the twelve issues into the standard binder which has been available in the past.

We are pleased to announce that a larger size of binder is now available which will hold the twelve issues published during 1929.

When ordering the larger size be sure to specify that the large binder is desired. They are available at $1.75 each and the member's name will be stamped on it for 50 cents additional. The smaller size binder is still available at $1.50.

Associate Application Form

For the benefit of members who desire to have available each month an application form for Associate membership, there is printed in the PROCEEDINGS a condensed Associate form. In this issue this application will be found on page XXXIII of the advertising section.

Application forms for the Member or Fellow grades may be obtained upon application to the Institute office.

The Committee on Membership asks that members of the Institute bring the aims and activities of the Institute to the attention of desirable and eligible nonmembers. The condensed form in the advertising section of the PROCEEDINGS each month may be helpful.

Radio Signal Transmissions of Standard Frequency

The following is a schedule of radio signals of standard frequencies for use by the public in calibrating frequency standards and transmitting and receiving apparatus as transmitted from station WWV of the Bureau of Standards, Washington, D. C.

Further information regarding these schedules and how to utilize the transmissions can be found on pages 10 and 11 of the January, 1930, issue of the PROCEEDINGS, and in the Bureau of Standards Letter Circular No. 171, which may be obtained by applying to the Bureau of Standards, Washington, D. C.

Eastern Standard Time	Oct. 20	Nov. 20	Dec. 22
10:00 P.M.	1600	4000	550
10:12	1800	4400	600
10:24	2000	4800	700
10:36	2400	5200	800
10:48	2800	5800	1000
11:00	3200	6400	1200
11:12	3600	7000	1400
11:24	4000	7600	1500

Committee Meetings

Committee on Admissions

The following meetings of the Committee on Admissions were held during the summer months:

July 9. Present R. A. Heising, chairman; R. H. Mariott, E. R. Shute, and H. P. Westman, secretary. Three applications for transfer to the Fellow grade were approved, four applications for transfer to the Member grade were considered and approved, and six applications for admission to the Member grade were considered, four of which were approved.

August 6. R. A. Heising, chairman; C. N. Anderson, J. S. Smith and H. P. Westman, secretary were present. An application for transfer to the Fellow grade and another for admission to the Fellow grade were considered and approved. Of three applications for transfer to the Member grade considered, two were approved and two of three applications for admission to the Member grade were approved.

September 3. Those present were R. A. Heising, chairman; C. M. Jansky, Jr., R. H. Marriott, E. R. Shute, A. F. Van Dyck and H. P. Westman, secretary. One of two applications for admission to the Member grade was approved and one application for transfer to the Member grade was approved of two considered.

Committee on Broadcasting

A meeting of the Committee on Broadcasting was held on September 3 in the office of the Institute the following being present: R. H. Marriott, acting chairman, B. R. Cummings, P. A. Greene, Raymond Guy, J. V. L. Hogan, and E. L. Nelson.

Standardization

Subcommittee on Methods of Test of the Technical Committee on Radio Transmitters and Antennas—IRE

This meeting was held at 10:00 A.M. on July 16 at the office of the Institute and was attended by William Wilson, chairman; F. G. Kear and Beverly Dudley, secretary.

Subcommittee on Nomenclature and Definitions of the Technical Committee on Radio Transmitters and Parts—ASA

A meeting of the above subcommittee was held at the office of the Institute on July 17 at 2:00 P.M. and was attended by R. M. Wilmotte, chairman; T. A. M. Craven, George Grammar (representing J. J. Lamb) William Wilson and Beverly Dudley, secretary.

Subcommittee on Nomenclature of the Technical Committee on Radio Transmitters and Parts—ASA

A meeting of this subcommittee was held in the King Edward Hotel

in Toronto, Canada, at 2:00 P.M. on August 19 and was attended by William Wilson, acting chairman; A. B. Chamberlain, J. J. Lamb and Beverly Dudley, secretary.

SUBCOMMITTEE ON METHODS OF TEST OF THE TECHNICAL COMMITTEE ON RADIO TRANSMITTERS AND ANTENNAS—IRE

A meeting of the above subcommittee was held at 2:00 P.M., August 20, in the King Edward Hotel, Toronto. William Wilson, chairman; F. G. Kear, D. G. Little, J. C. Schelleng, F. R. Lack, and Beverly Dudley, secretary were in attendance.

TECHNICAL COMMITTEE ON VACUUM TUBES—IRE

The following members were present at a meeting of the Technical Committee on Vacuum Tubes of the I.R.E. which was held at 10:00 A.M. on September 4 at the office of the Institute, Stuart Ballantine, chairman; F. H. Engel, D. E. Harnett, W. J. Kimmell (representing S. M. Kintner) B. E. Shackelford, J. C. Warner, R. M. Wise, and Beverly Dudley, secretary.

TECHNICAL COMMITTEE ON ELECTRO-ACOUSTIC DEVICES—IRE

A meeting of this committee which was held at 10:00 A.M. on September 10 at the office of the Institute was attended by H. A. Frederick, chairman; L. G. Bostwick, Paul Heyl, E. W. Kellogg, Benjamin Olney (representing R. H. Manson) W. P. Powers, A. E. Thiessen (representing Melville Eastham) H. A. Wheeler, Irving Wolff, and Beverly Dudley, secretary.

Institute Meetings

NEW YORK MEETING

The New York meeting of the Institute was held on Wednesday, September 3, 1930, in the Engineering Societies Building, 33 West 39th Street, New York City. R. H. Marriott presided.

A paper on "Aircraft Radio" was presented by A. K. Bohman, of the Pan American Airways, Inc. Several reels of motion pictures in connection with the paper were also presented.

Two hundred members and guests attended the meeting.

Errata

In the paper "A precise and Rapid Method of Measuring Frequencies From Five to Two Hundred Cycles Per Second" by N. P. Case, which appeared in the September, 1930, issue of the Proceedings, a footnote reference was omitted. This should appear on page 1586 and read, "Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce."

Part II
TECHNICAL PAPERS

Proceedings of the Institute of Radio Engineers
Volume 18, Number 10 *October, 1930*

SOME DEVELOPMENTS IN BROADCAST TRANSMITTERS*

By

I. J. Kaar[1] and C. J. Burnside[2]

([1]General Electric Co., Schenectady, N. Y. [2]Westinghouse Electric and Manufacturing Co., Chicopee Falls, Mass.)

DURING the spectacular development of the radio broad cast art in the past decade, little has been written regarding the progress of the art of transmission. Receiver problems have been copiously treated, and rightly so, for the demand for receivers is measured in millions of units whereas the demand for transmitters is, and must necessarily remain, very limited. In spite of the limited demand for transmitter equipment, research and development of this apparatus has kept abreast of the receiver art and it may be truthfully stated that to-day modern transmitters excel modern receivers in the fidelity with which they perform their work.

In order to visualize properly the development which has taken place in the past ten years, it is necessary to recall the class of equipment which was in service at that time. For the most part, transmitters were all of the "antenna oscillator" type, that is, the tubes generating the radio frequency were themselves coupled to the radiating system. Frequently these tubes were modulated in some fashion by operating upon their grids. This system was unsatisfactory in many respects and was soon improved by the use of separate modulator tubes operating to change the plate voltage of the oscillator. Due to troubles in coupling and frequency stability, this system was soon supplanted by the master-oscillator power-amplifier system which accomplished modulation on the plates of the final power stage by the constant current system. One of the next developments was the piezo-electric quartz crystal which was incorporated with the master oscillator to afford a degree of carrier frequency precision hitherto unheard of.

It should be observed that the development of broadcast transmitters has not been marked by revolutionary changes but has been the result of a steady painstaking study and improvement of details. During the radio-frequency circuit development described above, steady improvements were being made in pickup equipment and low-frequency amplifiers and also during this time the condenser microphone was brought to a stage of perfection. Vacuum tubes for specific

* Dewey decimal classification: R355.21×R550. Original manuscript received by the Institute, June 2, 1930. Presented before Fifth Annual Convention of the Institute, August 20, 1930.

purposes were made available. Circuits were carefully analyzed and improved. Lastly, engineering experience and confidence arose to a point where design work could be accomplished in much the same manner as is the custom in power practice.

The output power has steadily arisen from a few watts to 200 kw or more and no serious obstacle is seen to building transmitters of even greater power.

Considerable progress has been made in the method of transferring power to the antenna. This is now accomplished by means of high-frequency transmission lines which permit the building of the transmitter enclosure at a considerable distance from the antenna itself. This practice enables the transmitters to be located well out of the immediate field of the antenna. The transmission line behaves exactly like a low-frequency transmission line and it is necessary to take the same precautions, probably to a greater degree, at the terminals. It is interesting to note that a radio-frequency transmission line 1000 ft. long operating at 790 kc exhibits all of the phenomena of a 60-cycle power transmission line 2500 miles long except for the fact that the efficiency of the radio-frequency line is about 99 per cent whereas it is certain that there would be very little power left at the end of the 2500-mile line operated at 60 cycles.

Modulation

During recent years, it has been demonstrated that a great reduction in background noise could be brought about by completely modulating the transmitted carrier. This practice does not, of course, actually reduce the stray noise level but rather decreases its ratio to the received signal which is to the same end. This advantage is very noticeable on receivers whose detectors operate at low level and over considerable curvature since with these detectors, the received signal is, to a much greater extent, dependent upon the product of carrier and side-band amplitude and greater opportunity is afforded for extraneous noise to modulate the carrier.

Also, it is quite generally accepted that interstation interference due to heterodyning carriers can be a serious cause of disturbances over a much greater area than that covered by the modulation components of an incompletely modulated wave. A figure of merit for a transmitter may be defined as the ratio of the area over which it produces a satisfactory signal to the area over which it produces interference. The interference area remains constant for a given carrier amplitude whereas the signal area is proportional to some power of the degree of modulation. It is therefore observed that the

signal area of a completely modulated carrier most closely approaches that of the interference area.

Probably the most outstanding development of recent years has been in the method of modulation. At the present time, it is estimated that most of the existing broadcast transmitters are using the constant current system of high level modulation. This system is renowned for its simplicity, reliability, and high quality but suffers the disadvantage of not readily permitting complete modulation. In this system it is hardly possible to utilize properly the available capacity

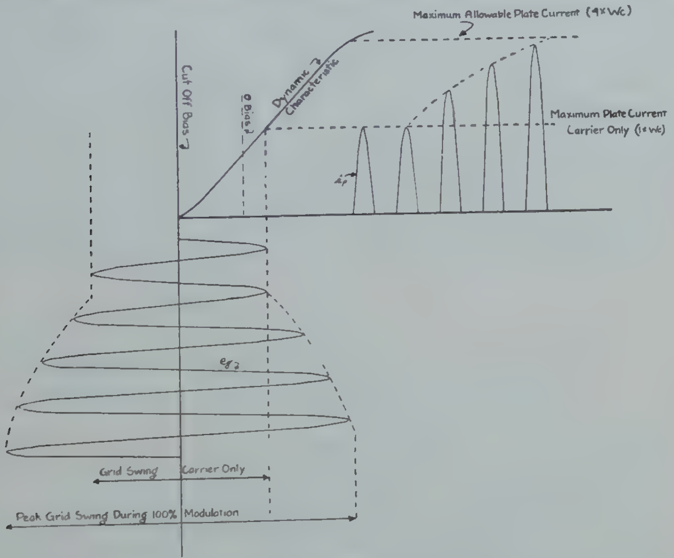


Fig. 1—General theory of class B amplifier operation.

of the modulators because of the difficulty in obtaining a proper impedance match between modulator and power amplifier. Transformers for this purpose are very expensive and suffer from frequency discrimination. It is commercially impractical to construct a transformer capable of performing this function at the power levels of modern transmitters. If, however, modulation is accomplished at a low power level and the resultant wave is amplified, a gain in over-all economy can be demonstrated and the output wave can be completely modulated. The power consumed by the modulators must, of course, be included in the total power drawn by the plate modulated system when comparisons are made of the two systems.

Class B Operation

A general idea of class B operation may be gained by reference to Fig. 1.

This figure indicates that the plate current drawn by the tube is very closely a linear function of the extent of the grid swing, differing

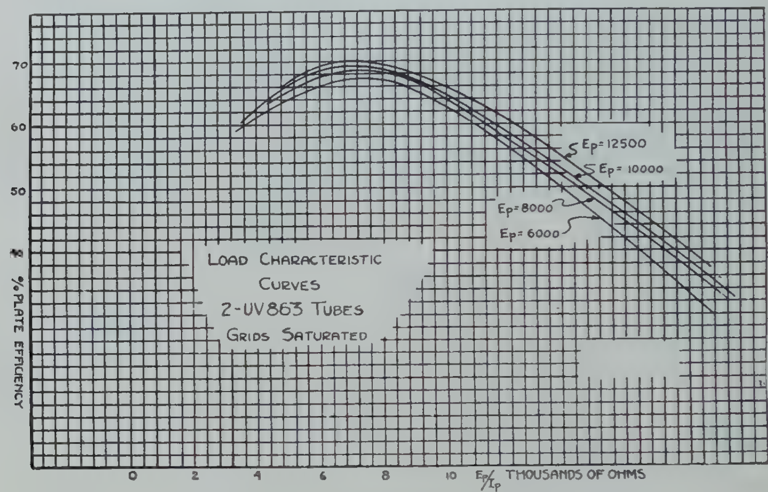


Fig. 2

only by the amount of curvature of the dynamic plate current characteristic. The curvature of the dynamic plate characteristic depends

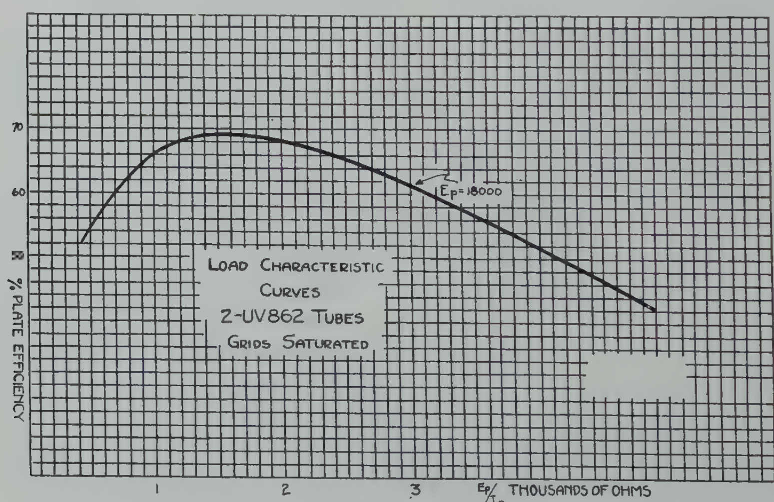


Fig. 3

upon the inherent characteristics of the tube and the ratio of the effective load impedance to the internal impedance of the tube. Under conditions of loading which give maximum conversion efficiency,

the dynamic characteristic is sufficiently linear to permit the plate current to be a linear function of the grid swing for all practical purposes. The transmitter is adjusted to operate into a value of load resistance as determined by Figs. 2 and 3. The position of the crests of these curves depends upon the physics of the tube and upon the power factor of the circuit to which it is connected. The curves shown are for typical circuits at broadcast frequencies. The conversion efficiency is also a linear function of the grid swing and consequently the output power is proportional to the square of the grid swing. This indicates that the instantaneous peak output of a transmitter during complete modulation is four times the output when the modulation is zero. It can be shown that the steady output under complete modu-

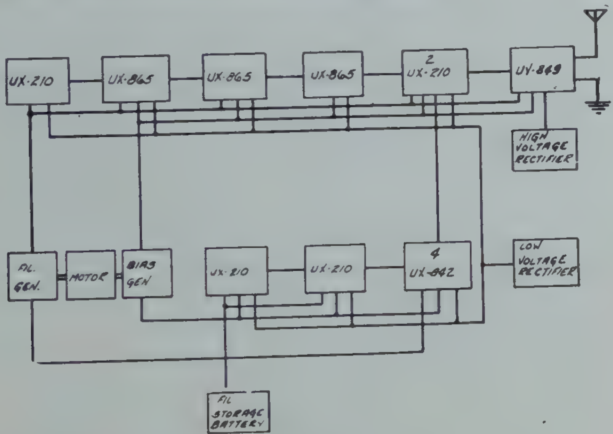


Fig. 4

lation is 1.5 times the output at zero modulation. The important consideration is, then, that even though the carrier power of a transmitter is only 50 kw, provision must be made in the tube complement permitting peaks of 200 kw to be supplied during peaks of complete modulation.

Type 100-A—100-Watt Class B Transmitter

This transmitter was designed to fill the need for an inexpensive high quality transmitter for use on shared channels or where the coverage desired is smaller than that possible by the use of the 5-kw or 1-kw transmitter.

Extreme frequency precision is afforded, the transmitter utilizing the same type of crystal control unit as is described as a part of the 5B and 50B transmitters.

A block diagram of this transmitter is shown by Fig. 4 and a skeleton schematic by Fig. 5.

Complete modulation of the carrier is achieved by low level modulation and class B amplification.

The transmitter unit is shown by Figs. 6 and 7.

Six radio-frequency stages are used employing tubes as follows:

Crystal stage	1—UX-210
Buffer stage	1—UX-865
First intermediate	1—UX-865
Second intermediate	1—UX-865
Modulated amplifier	2—UX-210's
Power amplifier	1—UV-849

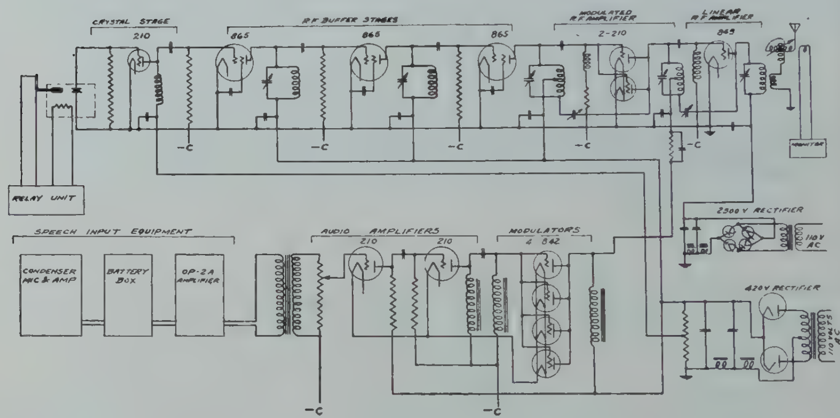


Fig. 5

The audio-frequency channel comprises two stages of amplification, the first being resistance coupled and the second being reactance coupled. Each stage employs a single UX-210 tube. The modulator bank employs four UX-842's in parallel. This tube has an amplification constant of three and is very well adapted to modulator service. Satisfactory impedance match between the modulator bank and the modulated power amplifier is obtained by a resistor-capacitor network through which the power amplifier draws its plate current.

Plate supply for all except the last stage in the radio-frequency chain is supplied from a single phase full wave rectifier employing two UX-866 hot cathode mercury vapor tubes. A rectifier using four UX-866 hot cathode tubes supplies plate voltage for the main power amplifier.

Bias supplies for all stages and filament supply to all except the two speech amplifier stages are obtained from a three unit motor generator set. Filament supply for the speech amplifier tubes is

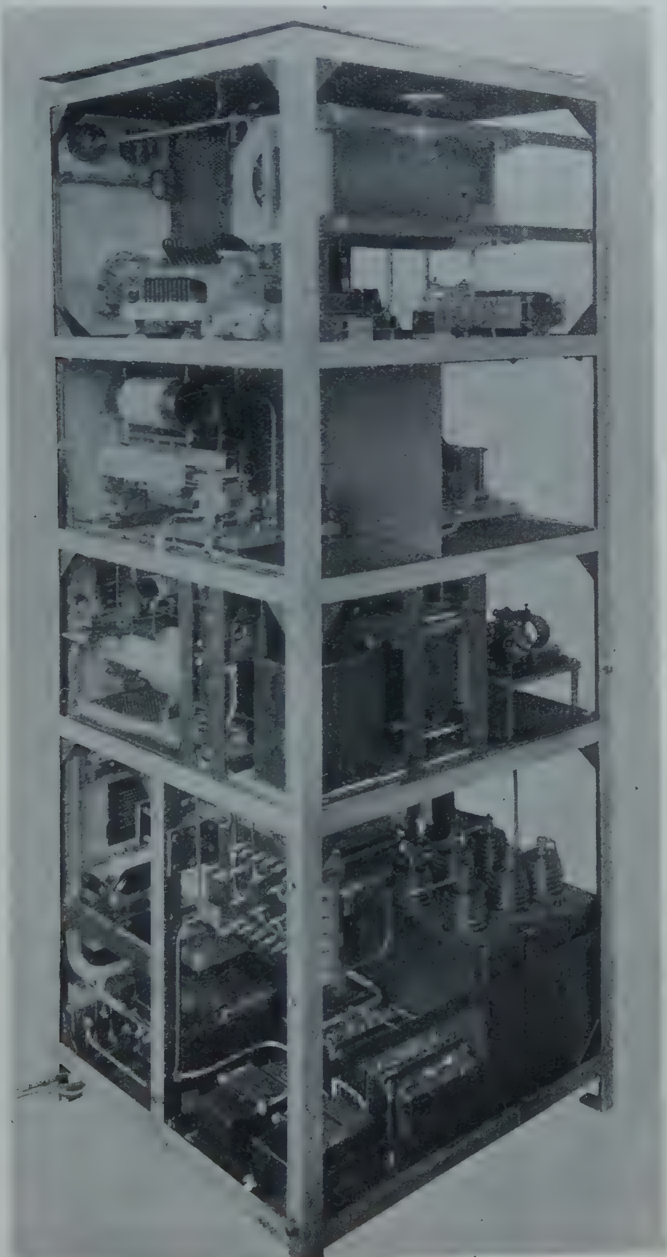


Fig. 6—100-watt broadcast transmitter. Rear view, shields removed.

obtained from the storage batteries which supply filament power for the speech input equipment.

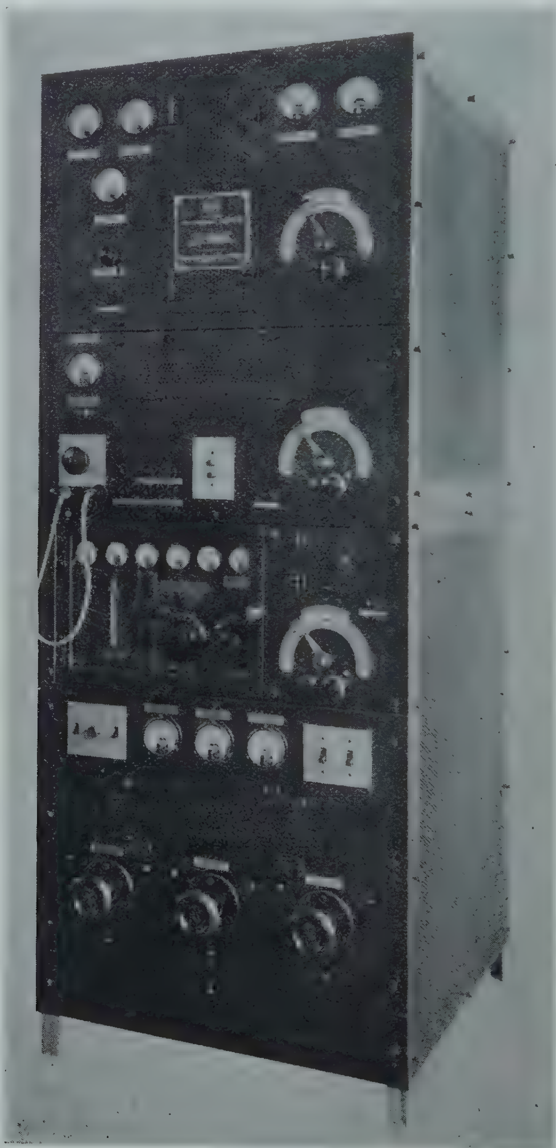


Fig. 7—100-watt broadcast transmitter. Front view.

Direct coupling to the antenna is used, with variometer and series condensers for tuning. With a few simple changes however, the set

can be adapted for transmission line feed in cases where this is advisable.

The over-all frequency characteristic does not deviate more than one db from a straight line between 70 and 5000 cycles. Percentage modulation is read directly by a meter on the panel of the transmitter. This unit is driven by the same monitoring rectifier tube which operates the loud speaker.

Type 1-B—One-kw Broadcast Transmitter

As a medium power member of the line of broadcast transmitters the type 1-B—1-kw broadcast transmitter has been developed. (See Fig. 8.)

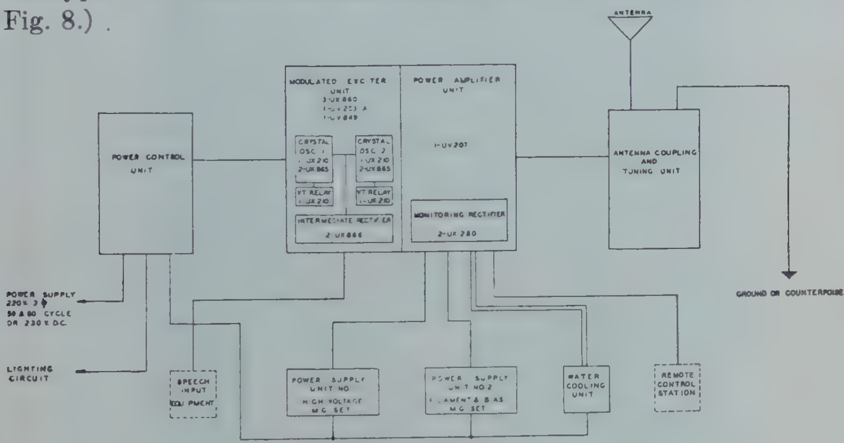


Fig. 8—Block diagram R.C.A. type 1-B transmitter.

This transmitter is of the linear amplifier type with modulation taking place in the stage preceding the output amplifier. This set is designed to operate at an unmodulated output of 1 kw and is capable of complete modulation. It is complete from audio input at zero level to the antenna, with water system, rotating power supply equipment, control panel, modulated exciter unit, power amplifier unit, and antenna coupling and tuning unit. A dummy antenna is also available for use with this transmitter.

Radio-Frequency Units

The radio-frequency units of the transmitter are:

(1) Modulated exciter unit
(2) 1-kw power amplifier unit
(3) Antenna coupling and tuning unit.

The transmitter proper is shown by Fig. 9.

(1) *The modulated exciter unit* contains two of the standard precision frequency units used in the other members of the RCA-Victor

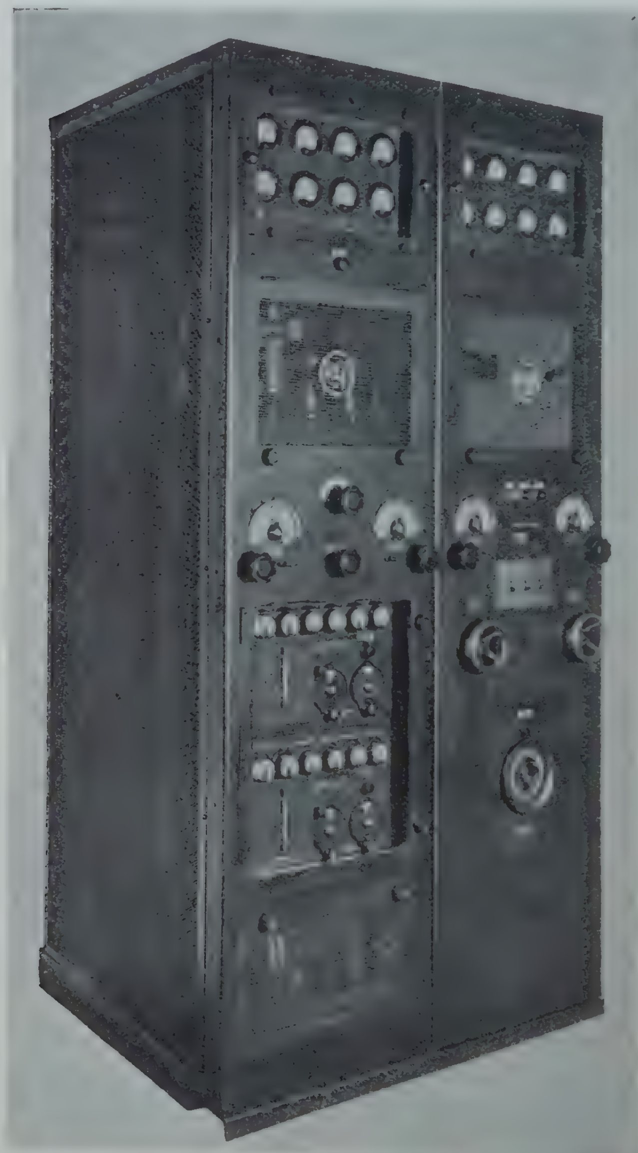


Fig. 9—One-kw broadcast transmitter. Left front view.

line of broadcast transmitters. Either of these units may be switched into the circuit by means of a panel control. A single phase full wave

rectifier utilizing two UX-866 tubes supplies power for the crystal unit in use.

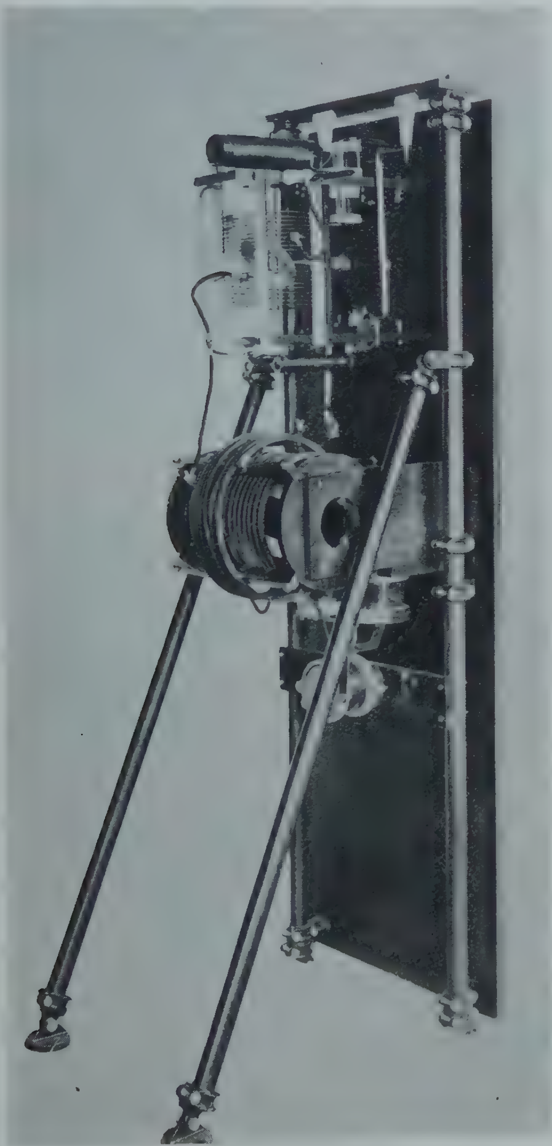


Fig. 10—Antenna unit. Rear view.

The crystal unit excites a buffer stage consisting of one UX-860 screen-grid Radiotron. This stage in turn furnishes excitation to the

modulated amplifier consisting of two UX-860's in parallel. A UV-849 Radiotron is utilized to modulate the two UX-860's in parallel.

A UV-203-A high level audio amplifier supplies excitation for the modulator grid, and operates directly from the audio line. Zero level audio input is sufficient to give complete modulation of the transmitter.

The modulated exciter unit also contains bias filter and potentiometer circuits, the vacuum-tube relays used in conjunction with the precision crystal units and other minor parts.

(2) *The 1-kw power amplifier unit* contains a water-cooled Radiotron operating at 6000 volts plate potential. This stage obtains its grid excitation directly from the modulated stage in the modulated exciter unit. The plate tank circuit has a coupling coil to which the transmission line is connected. The 1-kw power amplifier unit also contains a monitoring rectifier for monitoring the r-f output and indicating percentage modulation. The power supply filter circuit is also contained in this unit.

(3) *The antenna coupling and tuning unit* consists of a transmission-line-terminating tank circuit with antenna coupling coil and antenna tuning inductance, an antenna series condenser, and an antenna ammeter. A thermocouple on this unit gives an antenna current indication on the 1-kw power amplifier meter panel. A rear view of this unit is shown by Fig. 10.

Power Equipment and Cooling System.

The power equipment and cooling system includes the following units.

(1) Power control panel
(2) Plate supply motor-generator set
(3) Filament and bias motor-generator set
(4) Water-cooling system.

(1) *The power control panel* is designed for installation in the power room where the plate and filament motor-generator sets and water-cooling system are located. It is of the panel type and on it are mounted all power switches, fuses, contactors, and control relays together with the line starters for the filament and plate motor-generator sets. Panel lights to indicate blown-out fuses are also a feature of this unit. A view of this unit with protecting screen open is shown by Fig. 11.

(2) *The plate supply motor-generator set* is also a three-unit machine consisting of motor and two double commutator 3000 volt d-c generators. Each commutator handles 1500 volts and as the machines are operated in series the various plate voltages of 1500 volts, 3000

volts, and 6000 volts, required by the transmitter are available directly without the use of potentiometers or series resistors.

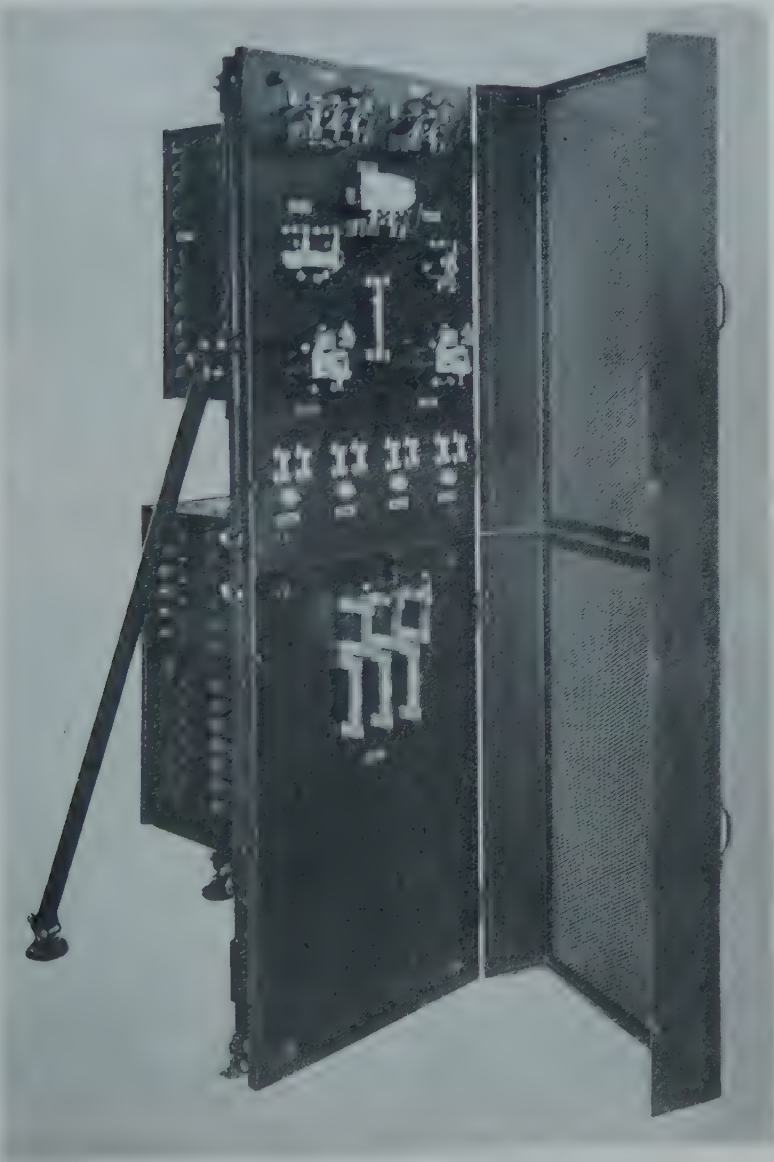


Fig. 11—Power control unit.

(3) *The filament and bias motor-generator set* is a three-unit machine consisting of motor, filament generator, and exciter. The exciter

furnishes field excitation for the filament generator and also for the plate supply generators. It is used for a bias supply also.

(4) *The cooling system* consists of a centrifugal pump, radiator, and fan, with common driving motor all mounted in one compact unit. This unit will dissipate 4 kw continuously. An expansion tank and visual water-flow indicator complete the system.

The complete transmitter is automatic in operation and starts with a single push button. All units start up in regular sequence and at the proper time interval from this single control. Control switches make it possible to halt the starting sequence at several points in the procedure for purposes of test or stand-by adjustment. Less than 15 seconds are consumed from the pressing of the start button until the transmitter is on the air at full power. The total

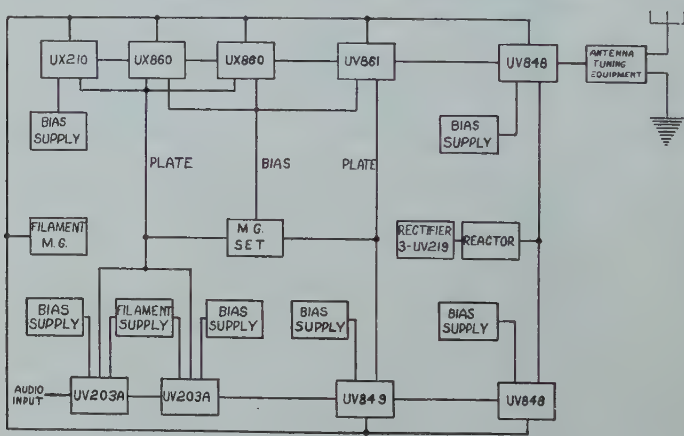


Fig. 12

power drawn from the line by this transmitting equipment is slightly less than 13 kw.

The perfection of performance of this transmitter is the same as that of the 5-kw type 5-B and 50-kw type 50-B transmitters.

Type 5-A—5-kw Class C Transmitter

The first 5-kw broadcast transmitters built by the manufacturing companies of the R.C.A. were plate modulated on the output amplifier stage. A considerable number of these transmitters have been built and are giving satisfactory service.

It is possible to modulate the carrier of this set to approximately 70 per cent without serious limiting, the amplitude of the second audio harmonic being about 2 per cent at this degree of modulation.

This transmitter was the first of its kind to utilize four-element tubes in its radio-frequency amplifier chain. Only the power stage

requires neutralizing, this stage using a three-element water-cooled tube.

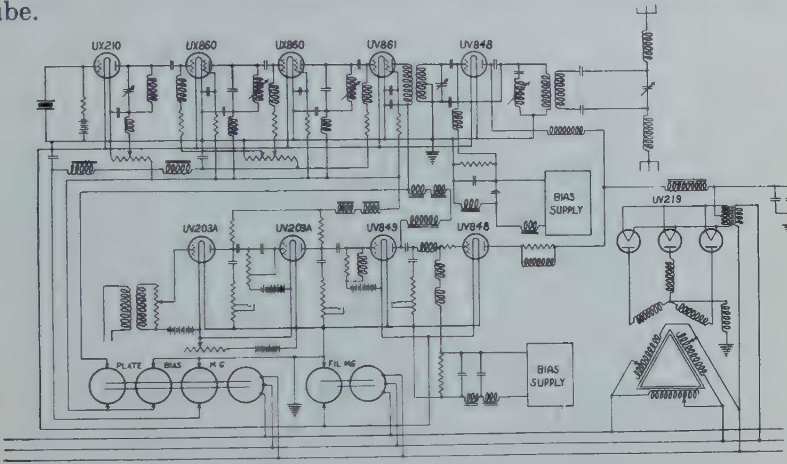


Fig. 13

Piezo-electric quartz crystal control is used, the crystal operating in the grid circuit of a UX-210. The crystal stage drives a UX-860

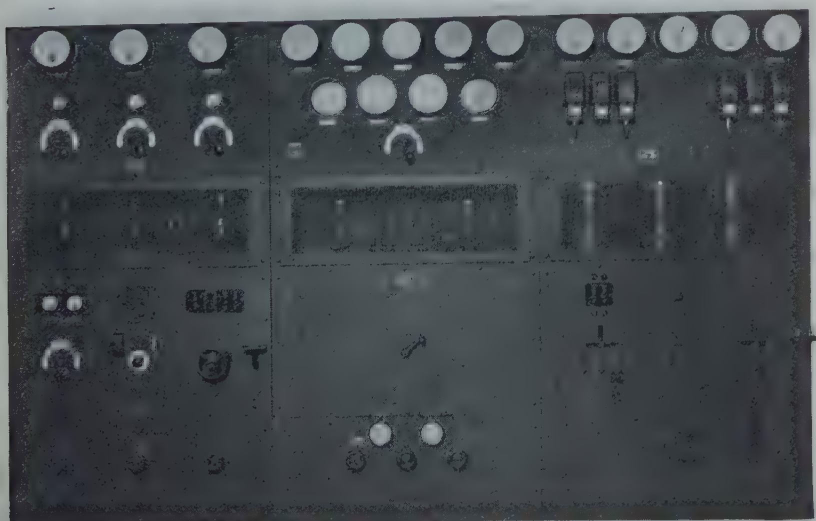


Fig. 14—Five-kw broadcast transmitter, crystal controlled amplifier, modulator power amplifier, and rectifier.

four-element tube of 75 watts capacity which acts as a buffer between the crystal stage and the next UX-860 stage. The second UX-860 drives a UV-861 four-element tube which has an output rating of

400 watts. The UV-861 stage is inductively coupled to the grid of a UV-848 water-cooled Radiotron which has an output rating of 20 kw.

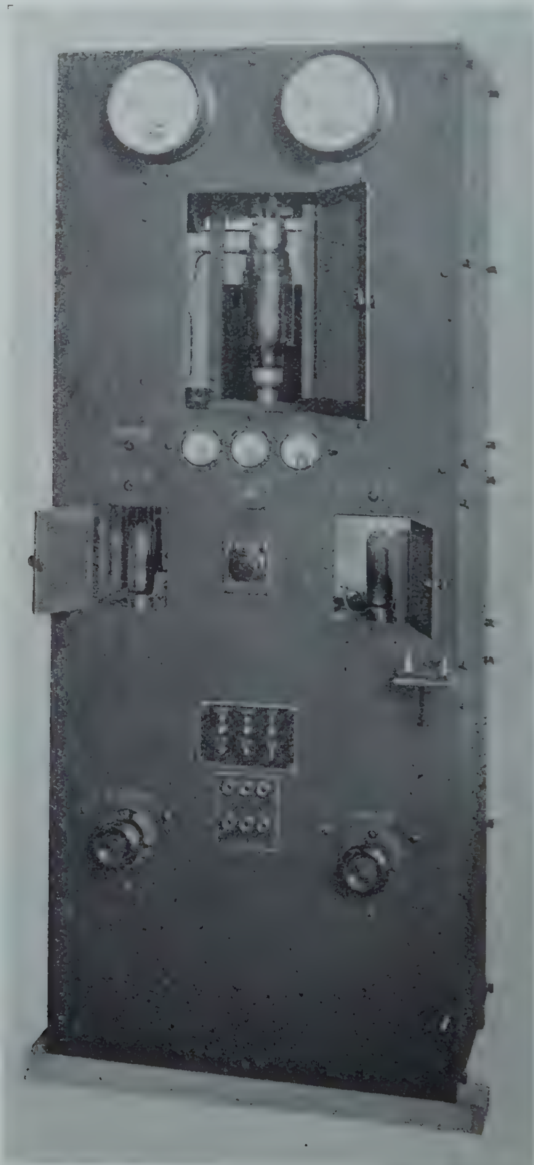


Fig. 15—Audio amplifier with doors open.

This stage is inductively coupled, via a high kva tuned circuit, to a transmission line and thence to the antenna.

All stages of the radio-frequency chain, except the buffer, are driven to grid saturation and operate as class C amplifiers wherein the plate current flows for only a small fraction of a cycle.

The audio-frequency channel takes audio material from the line or from the line amplifiers at approximately −10 db. Two UV-203-A

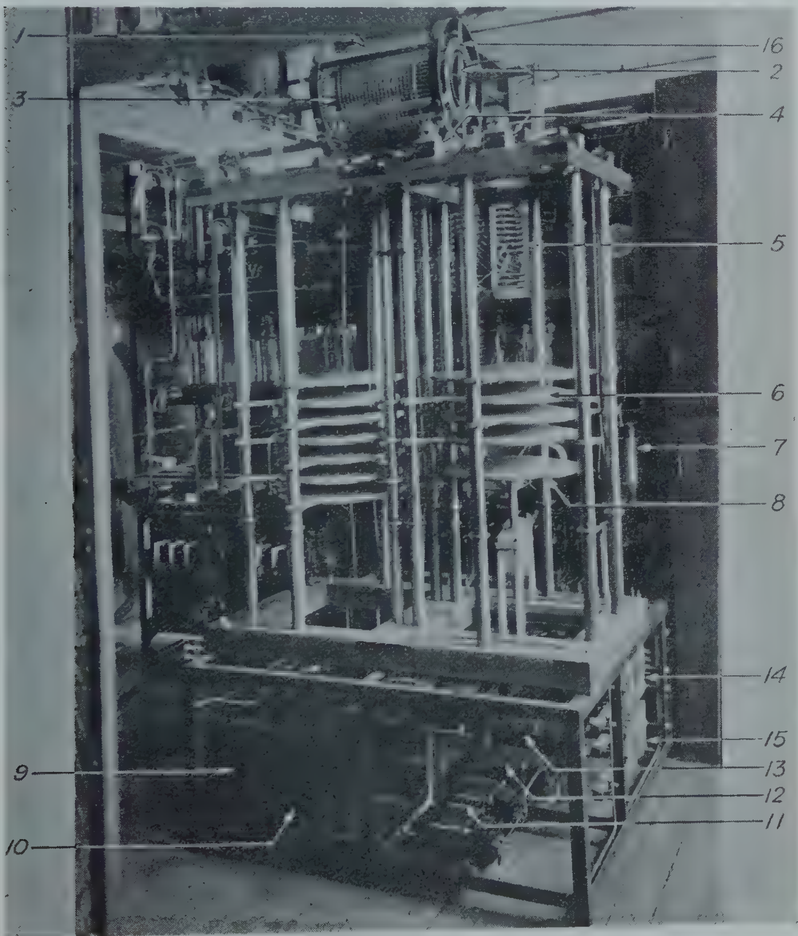


Fig. 16—Modulator power amplifier. Rear view. Tank assembly.

resistance coupled amplifiers and a UV-849 reactance coupled amplifier raise this level sufficiently to swing the grid of a single UV-848 water-cooled modulator over its useful class A range. The modulator plate is coupled to the power amplifier plate by a modulation reactor whose size is sufficient to prevent attenuation, to any marked degree, of audio frequencies as low as 30 cycles. (See Figs. 12 and 13.)

The transmitter is built behind three main panels as shown by Fig. 14. The left-most panel mounts the crystal controlled oscil-

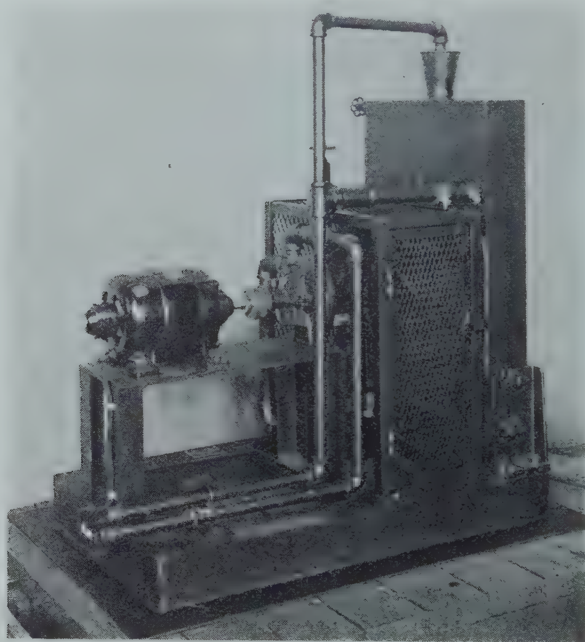


Fig. 17—Water-cooling unit.

lator and the low level radio-frequency amplifiers. The middle panel houses the main power amplifier and the modulator tubes and their

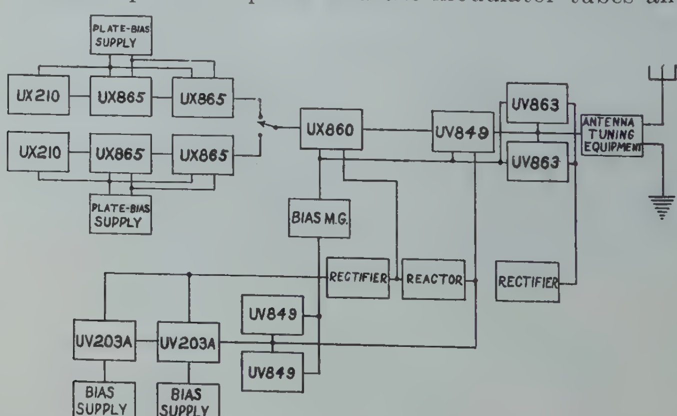


Fig. 18

circuits. The right-most panel mounts the high voltage rectifier. This rectifier is of the three-phase half wave type and employs three

UV-219 high vacuum rectifier tubes. The audio amplifiers are located in a separate assembly as shown by Fig. 15.

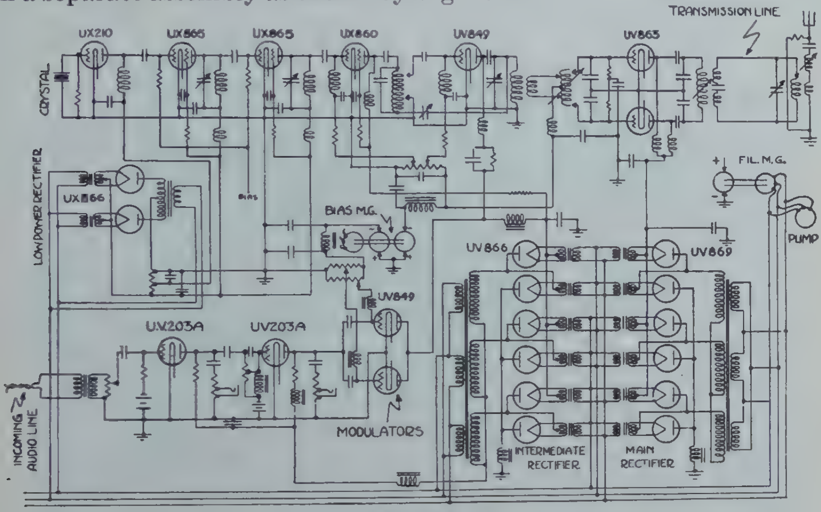


Fig. 19

All of the high level radio-frequency circuits are located on a separate assembly behind the center panel. This equipment includes

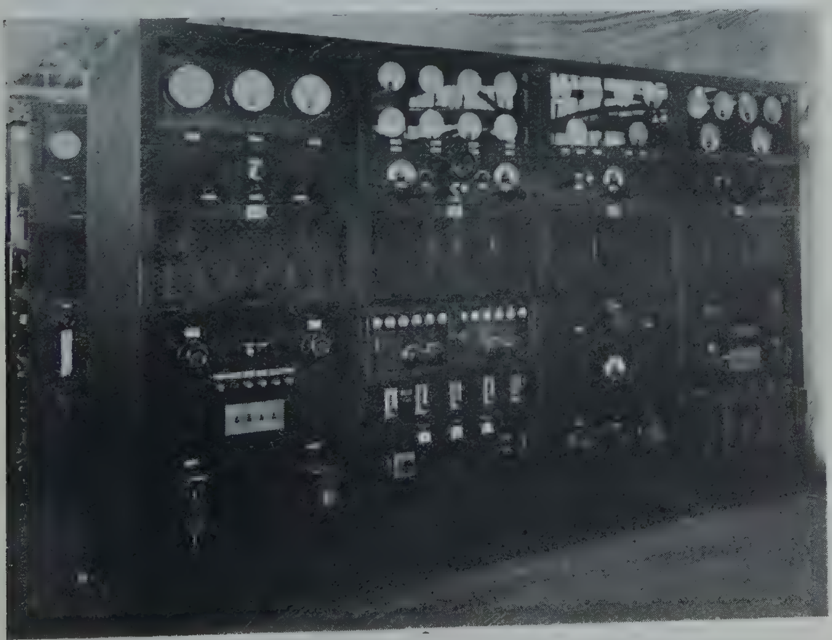


Fig. 20—Five-kw broadcast transmitter. Front view.

the air dielectric main tank capacitor, the transmission line coupling transformer, and the tuning variometer. (Fig. 16.)

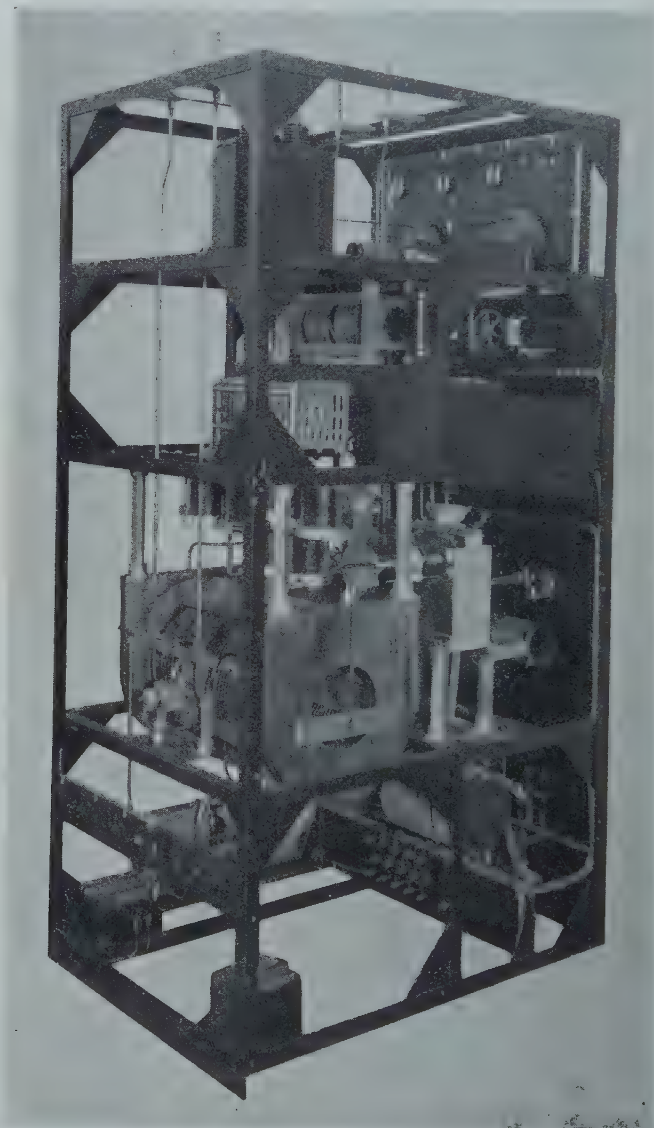


Fig. 21—Power amplifier, 5-kw broadcast transmitter. Rear view.

Cooling water is circulated by a unit pump-blower-radiator unit as shown by Fig. 17.

Type 5-B—5-kw Class B Transmitter

This transmitter was designed to fill the need for a medium power broadcast transmitter affording extreme frequency precision and the

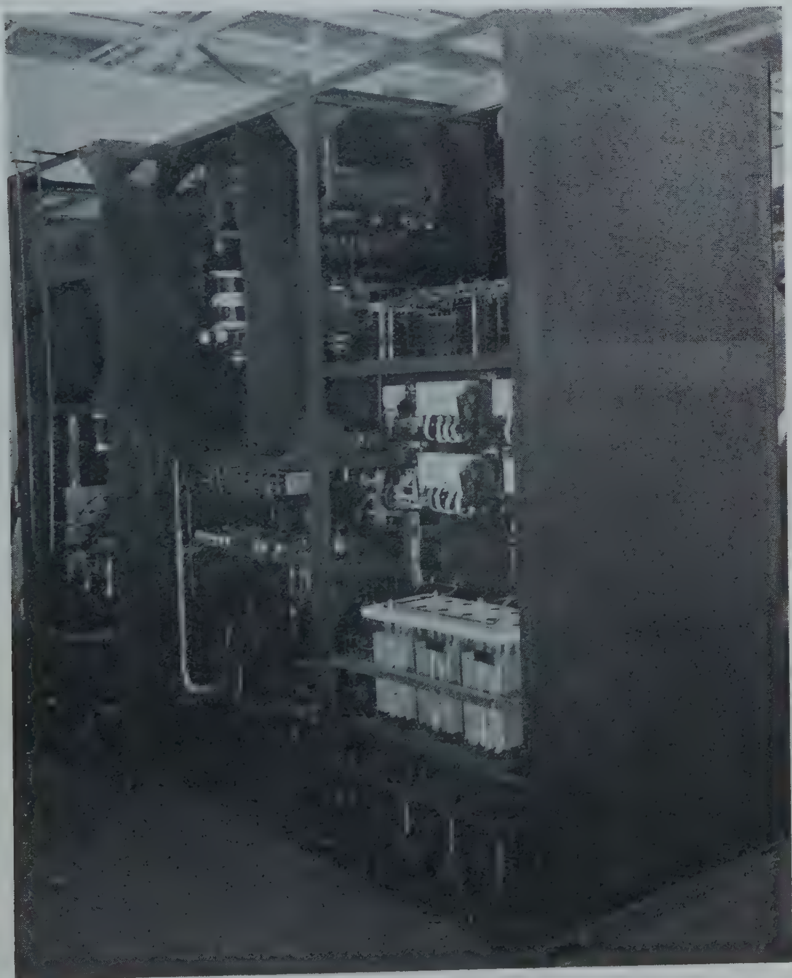


Fig. 22—Five-kw broadcast transmitter. Rear view showing interior.

advantages of 100 per cent modulation. The transmitter is similar in many respects to the one just described and which it supersedes. A block diagram of this transmitter is shown in Fig. 18, and a skeleton schematic is shown by Fig. 19.

This transmitter was designed with the following points in mind:

1. It should be a step in advance of the most rigid possible requirements of frequency control.
2. It should be automatic, simple and foolproof in operation.
3. It should be capable of complete modulation.
4. Harmonic transmission should be well below that required for operating in accordance with recommendations of the I.R.E.
5. The quality of its transmission should be far beyond that necessary for modern receivers of the present or immediate future.

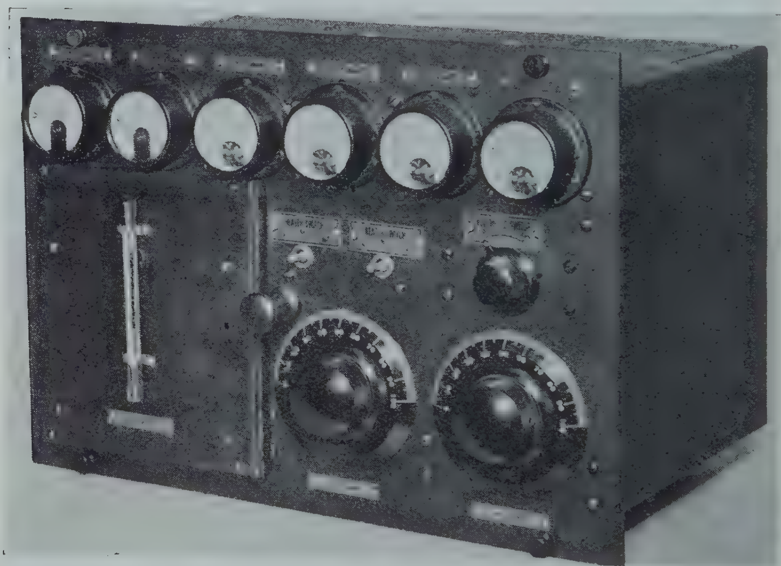


Fig. 23—Quartz crystal oscillator amplifier unit. Front view with all shields on.

The design has been carried out with these points in mind and with the additional precautions necessary to assure economical and reliable operation.

Fig. 20 shows a front view of the 5-B transmitter. Four major assemblies comprise the complete equipment. From left to right, the first unit mounts the intermediate plate rectifier and controls, the next panel mounts the two crystal oscillators, the low level radio-frequency stages, the audio-frequency amplifiers, the modulators, and the modulated amplifier. The third panel mounts the main power amplifier and the end panel houses the main rectifier. An idea of the construction of the power amplifier radio frequency circuits may be obtained from Fig. 21, while the rear of the complete assembly is shown by Fig. 22.

Radio-Frequency Channel

The crystal controlled stage, its buffer stage, and first amplifier are supplied in duplicate together with their plate supply rectifiers and provision is made to switch rapidly from one to the other unit. Provision is also made to switch to a stand-by position for periods when the remainder of the transmitter is not operating. In this position the filaments of the crystal tube, buffer, and amplifier are lighted by alternating current and are thus independent of the d-c generator. It is thus possible to keep the crystal stages operating continuously

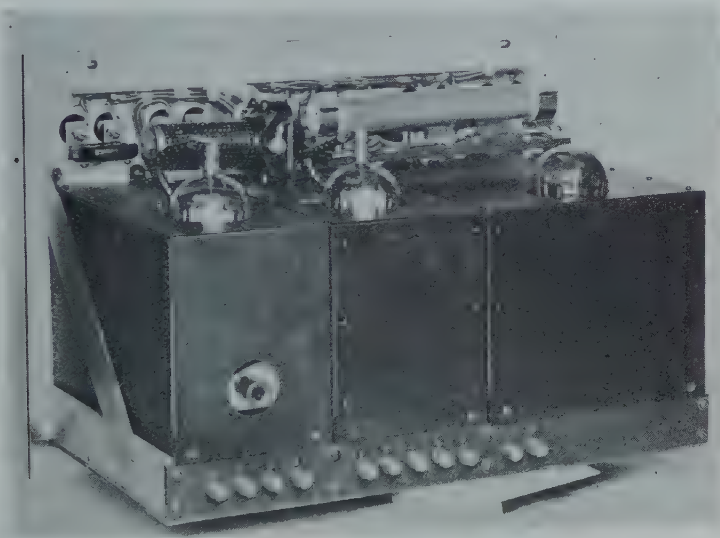


Fig. 24—Quartz crystal controlled oscillator amplifier unit. Rear view with interstage shields on.

in order to insure constant temperature and operating conditions. The crystal compartment and associated apparatus are shown by Figs. 23 and 24.

The crystal oscillator amplifier unit embodies some features which are not usually found in commercial transmitters. The quartz crystal itself is mounted in a separate holder, the two plates of which are made of heavy blocks of monel metal. The adjacent surfaces of these plates are ground and lapped so as to be perfectly smooth and flat. The spacers which hold these plates apart are made of quartz so that any variation in temperature will give approximately the same expansion in the spacers as in the quartz crystal itself. This assures accurate and constant spacing of the holder plates with respect to the crystal.

The crystal and its holder are contained in an oven, the temperature of which is maintained approximately constant by means of a sensitive mercury thermostat and relay system. Variation in ambient temperature in the order of 15 or 20 deg. C give an inappreciable variation in the crystal temperature. The two crystal amplifier assemblies are accessible from the front and are housed behind two glass doors which can be locked.

Considerable effort has been expended to insure constant frequency from these crystal units. The crystal tube, a UX-210, drives an untuned plate circuit which is capacitively coupled to a four-element UX-865 buffer tube. This tube is not driven far enough to take grid current and thus the crystal controlled tube runs with practically no load. The four-element buffer tube insures absence from regeneration to the crystal controlled tube or feed-back from the higher power stages of the transmitter. The third tube of the assembly is also a four-element UX-865, which draws grid current during operation and which raises the power level sufficiently to drive the UX-860 following. Plate supply for the two crystal controlled units is obtained from two single phase full wave rectifiers utilizing the UX-866 hot cathode mercury vapor rectifier tube in a full wave circuit.

Duplicate crystal units are supplied and the control of the transmitter may be switched to either crystal unit. This arrangement makes it possible to change frequency readily in the case of a re-allocation of wavelength or allows the operator to return the complete crystal unit to the manufacturer for calibration or adjustment. It also provides an additional safety factor in the correction of possible failure of one of the crystal units. As each crystal unit has its own plate supply no fluctuations resulting from disturbances in other parts of the transmitter can be transmitted back to the crystal unit as would be the case if a common plate supply were used.

The UX-860 tube, driven from the second UX-865 supplies an output power capable of maintaining grid saturation of the UV-849 which it drives and which is the modulated stage. Plate voltage for the UX-860 and for the UV-849 stages is supplied by a rectifier utilizing six UX-866 hot cathode rectifier tubes in a three-phase full wave circuit. Plate voltage for the UV-849 stage is, of course, supplied through a modulation reactor and also through a resistor-capacitor unit which lowers the axis about which the plate of the UV-849 operates, enabling it to be modulated completely by the two UV-849 modulator tubes. This stage operates in class C. The UV-849 stage drives the grids of the two UV-863 tubes over a short transmission link. The UV-863 is a water-cooled three-element tube having a maxi-

mum plate dissipation of 10 kw each. This stage operates as class B and special precautions are taken to insure its proper performance in this class. The grid circuit is artificially loaded to insure good regulation from the driving source over that portion of the cycle when the driven grid is positive. The tubes operate in a balanced circuit, the plate and grid circuits both being tuned.

It is extremely important in an amplifier of this kind to prevent regeneration from plate to grid circuit and to preclude the possibility of parasitic or self oscillations existing during any part of the grid swing. Such spurious oscillations may exist in an otherwise normal amplifier and may not be evident to casual inspection, disappearing entirely when grid excitation is removed. Trouble from this source is one of the serious objections to the class B amplifier where the grid is positive for a considerable portion of the cycle (practically 180 deg.), and trouble from this source is undoubtedly the outstanding problem to be faced in building extremely high power transmitters using class B amplification.

A great deal can be accomplished toward the prevention of parasitic oscillations by the proper design of the high-frequency circuits. Care must be taken to provide paths from plate and grid to ground through capacitors whose reactances are low at parasitic frequencies. The leads between separate units of the high-frequency system must be kept short and for this reason as much of the circuit as possible is built integral with the tube jackets themselves. The grid tuned circuit capacitors are connected directly to the grid stems of the tubes and to the filament chokes. Care is taken to insure that the plate and grid parasitic tank circuits are detuned with respect to one another, the grid circuits being preferably capacitive with respect to the plate.

It has been shown to be possible to stabilize a power amplifier stage by the use of damping networks properly connected in the circuits. The complication involved by this method of stabilization was realized at the outset of the present designs and considerable study was given to the proper stabilization of the amplifier circuits without requiring the use of these stabilizing networks. The finished design is remarkably stable and free from any tendency toward parasitics or self oscillation. Stabilization of the UV-863 stage against fundamental frequency oscillation is accomplished by means of a balancing network not shown in the schematic diagram.

The plate and grid inductors are tuned by means of rotating metallic "doughnuts" very tightly coupled to the coil and which operate to decrease the inductance of the coil depending upon their angular position. Mica capacitors are used in both tuned circuits.

These are tapered in size to allow proper tuning at any wavelength in the broadcast band.

The antenna is fed by means of a transmission line which terminates in a tuned circuit whose constants, together with the coupled-in resistance of the antenna, are proportioned to terminate the line in its characteristic impedance. As the angle of the transmission line is very small, the termination is therefore entirely real. The closed tuned circuit at the line termination is a very flexible means of adjusting the terminal impedance and also acts very materially to reduce harmonic radiation from the antenna.

The ratio of the power radiated on the fundamental to that radiated on any harmonic is well in excess of the recommendations laid down by the I.R.E. The system used also lends itself very nicely to any further reductions which may be required as a result of more stringent regulation by the Federal Radio Commission.

Antenna current and amplifier tank current are both read by meters located on the front panels. These meters are fed by radio-frequency current transformers.

The main rectifier utilizes six UV-869 hot cathode rectifier tubes connected in a three-phase full wave circuit. This circuit has many advantages when operated with hot cathode mercury vapor tubes. For instance, it is quite possible to produce a rectifier whose over-all conversion efficiency is in the order of 95 per cent and whose regulation no load to full load is less than 8 per cent. Two tubes are effectively in series so that the inverse peak voltage is divided between two tubes. It should be observed that the inverse peak voltage to which a tube is subjected is only 1.045 times the d-c voltage whereas it is 2.09 times the d-c voltage for a half wave three-phase rectifier. The advantage of "double ended" rectifier circuits can only be realized when using mercury vapor tubes since, because there are two tubes in series, the space change drop would be prohibitive when using high vacuum tubes. The space change drop of this mercury vapor tube is only 20 volts and is practically independent of current.

Audio-Frequency Channel

Audio power is received from the line or from line terminating apparatus at a level of approximately -10 db and is amplified in two UV-203-A stages to a level sufficient to drive the two UV-849 modulator tubes. Equalization is effected in the grid circuit of the second stage. Both stages are resistance coupled. The two modulator tubes have a low amplification constant and are capable of delivering 100

watts each of undistorted audio power. This is well capable of modulating the single UV-849 amplifier completely.

The possibility of "picking up" modulation in the last amplifier by biasing beyond cut-off is utilized only to a very slight degree, the bias of this stage being held, as closely as possible, exactly at cut-off.

Operation of the Transmitter

The transmitter itself, independent of the audio-control equipment, may be operated from an operator's control box containing two sets of start-stop push buttons and a switch. With the switch in the full automatic position the first start button will put the transmitter in operation with full automatic control, from the starting of the water pump to the application of the plate voltage to the output stage. Throwing the switch to the "stand-by" position on the operator's control panel starts the station up through its regular sequence to the point where the plate voltage from the main rectifier is applied. The second start button must then be pressed to apply the high voltage power. The starting of the transmitter follows a regular sequence in which time delay relays and interlocks control the timing and starting of each successive stage. For example, the pressing of the start button places the water pump and cooling fans in operation. When the water flow is up to normal value the filament and bias machines are started. A slow build-up feature in the filament machine prevents the cold filaments of the tubes from taking excessive current. When the filaments are up to normal voltage, plate voltage is applied to the crystal oscillator unit. There is then a slight time delay before the buffer amplifier and modulated amplifier are energized. The operation of these stages is followed immediately by the application of the main rectifier plate voltage. A series of switches located on the low power rectifier and control panel may be used to open the control circuit and halt the starting of the transmitter at any one of several stages in the starting operation. This allows considerable flexibility for testing and initial adjustment.

Performance

The frequency response of the transmitter is practically flat between 30 and 10,000 cycles, falling off a maximum of 2 db at both extremes. With care, the system may be equalized to be flatter even than shown by Fig. 25. This is not necessary, however, when it is realized that a difference in level of 2 db is hardly recognizable by the ear especially at the extreme ends of the audio spectrum.

It is to be observed that a decided improvement in low-frequency

response is effected by the use of a main rectifier utilizing hot cathode rectifier tubes. In a high vacuum rectifier system the filter condenser must be relied upon almost entirely for maintaining the output voltage

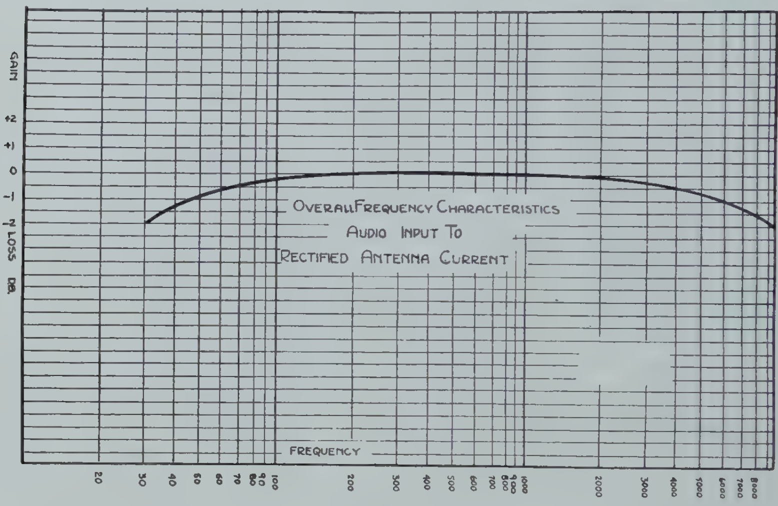


Fig. 25

of the rectifier during peaks of power supplied. To fulfill properly the requirements at the lowest audio frequencies, a large filter condenser is required, since the rectifier circuit cannot be depended upon to maintain its terminal voltage under load. The hot cathode rectifier,

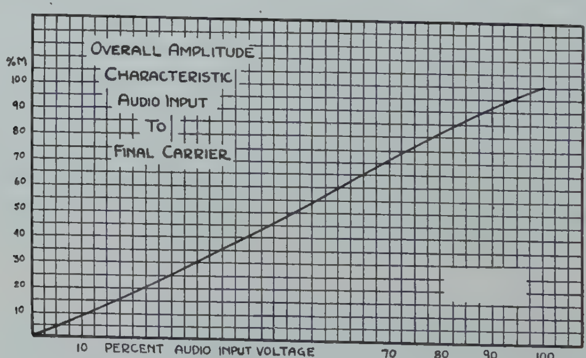


Fig. 26

because of its exceptional regulation can be utilized to some extent to supply peaks of power at very close to no-load voltage. The size of the filter condenser can, therefore, be decreased, or an improvement can be demonstrated in the low-frequency characteristic by employing

the same size filter condenser as ordinarily would be used in connection with a high vacuum rectifier. This gain, of course, is increasingly less evident the larger the series smoothing reactor becomes.

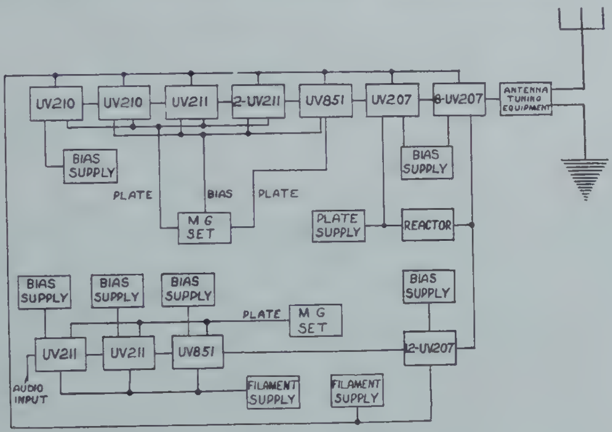


Fig. 27

The modulation characteristic is quite satisfactory as shown by Fig. 26 wherein percentage modulation of the carrier is plotted against audio input.

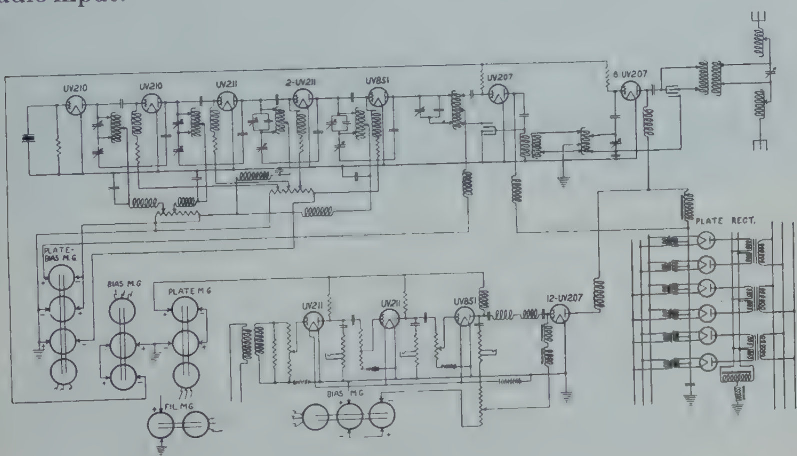


Fig. 28

Type 50-A—50-kw Class C Transmitter

During the latter part of 1926 a well-known broadcast company voiced a need for a high power broadcast transmitter for one of their networks to supplement an existing high power transmitter

on their neighboring network. The nominal rating was to be 50-kw. Such a transmitter had been developed some time previously and a model had been in operation long enough at one of the manufacturing plants to insure its reliability. Early in 1927 work was started on the design of a commercial model practically duplicating the developmental model mentioned and in September, 1927, this transmitter was turned over to the Broadcasting Company. (Figs. 27 and 28.)

Seven main units of the transmitter are mounted on the main floor of the power house as follows:

1. The crystal controlled low level radio-frequency amplifier
2. The intermediate power ampilfier
3. The main power amplifier
4. The modulator bank
5. The main rectifier
6. The main switchboard
7. The operator's control table.

Fig. 29—Broadcast station employing type 50-A transmitter. View shows main transmitter room.

A general view of the main floor of a typical installation using this equipment is shown by Fig. 29.

The high level audio amplifier (supplied in duplicate) and the line amplifier and monitoring apparatus are mounted in the control room which adjoins the main transmitter room.

All of the power equipment such as transformers, rotating machinery, pumps, etc., are mounted in the basement giving an operating room free from noise and vibration.

The Low Level Radio Frequency Amplifier

This unit comprises a quartz crystal controlled oscillator and four stages of class C amplification.

The crystal oscillator is a UX-210. This is followed by a UX-210 buffer stage, a UV-211 50-watt stage, a 2 UV-211 100-watt stage, and a UV-851 1-kw stage.

The Intermediate Power Amplifier

A short transmission line connects the output of the low level amplifier to the grid of a single UV-207 water-cooled tube. This stage also operates in class C.

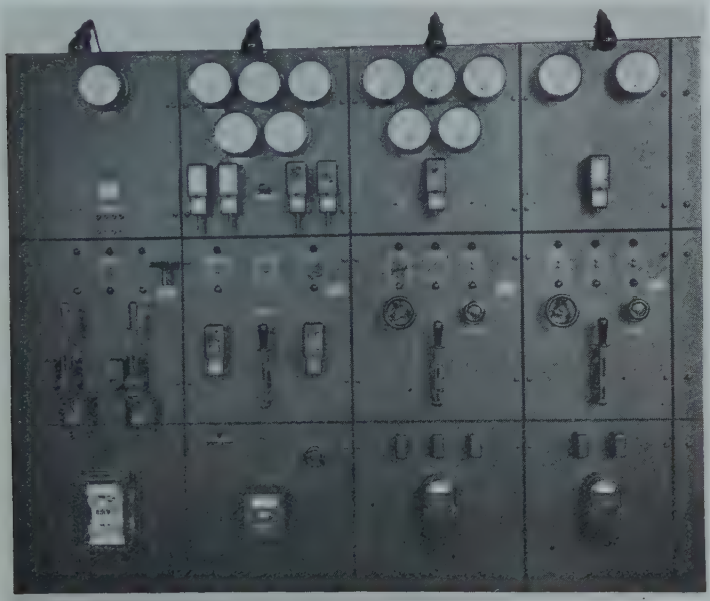


Fig. 30—Front view, control panel.

The Main Power Amplifier

This unit mounts 10 UV-207 tubes in parallel. Eight of these tubes are used in service while two are reserved for spares. Any tube may be switched into or out of service from the operator's control table.

This unit is plate modulated and receives its plate supply through a battery of modulation reactors located in the basement.

The Modulator Unit

This unit mounts 16 UV-207 tubes in parallel. Twelve tubes are active and four are held as spares. These tubes are connected in pairs, and it is possible to switch any pair into or out of service from

the operator's table. Twelve tubes provide capacity capable of modulating a 50-kw output to 60–70 per cent.

The Main Rectifier

The rectifier supplying plate power to the modulator and output power amplifier utilizes 6 UV-214 high vacuum water-cooled kenotrons in a six-phase double Y connection. Four single-phase plate transformers are supplied, three being active and one being held for spare. Output voltage is controlled by a primary induction voltage regulator.

Fig. 31—Main floor, installation, 50-kw type 50-B broadcast transmitter.

The Main Switchboard

On this unit are mounted all of the controls for the transmitter. (Fig. 30.) There are four sections comprising the panel as follows:

A. Power input
B. Rectifier panel
C. Power amplifier control
D. Modulator control.

The Operator's Control Unit

This is a small unit which mounts directly on the operator's control table. Only such controls are mounted on this unit as are required after the station has been put into operation. Provision is made on this unit to switch spare tubes into service in the event of failure during program.

A typical high power transmitter rated at approximately 40 kw designed at an earlier date, has been in operation at WJZ, Bound Brook, N. J., since 1925. This transmitter has been described in detail before the Institute.

Type 50-B—50-kw Class B Transmitter

The trend of development toward higher power has brought out the necessity for vacuum tubes of such a size that a multitude of tubes would not be required by a high power transmitter. For this use the UV-862 Radiotron has been developed. This tube is capable

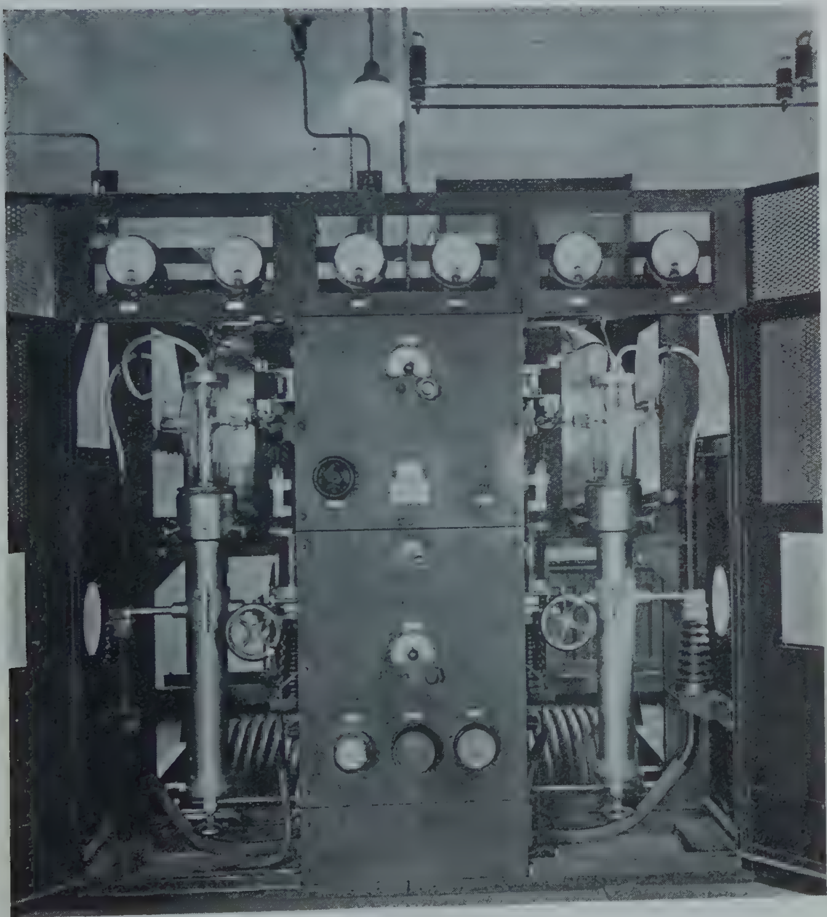


Fig. 32—Main power amplifier with doors open.

of an output of 100 kw under average conditions. This tube has made possible the handling of large amounts of power at radio frequencies without the complications which have previously been introduced by the operation of tubes in parallel. The development of this tube has made possible the design of the class B 50-kw transmitter. (Fig. 31.)

To supply the d-c power for these tubes, a new type of rectifier has also been developed and is now available as the UV-857 hot cathode mercury vapor tube. This tube, recently described in a paper presented before this society, is rated at 20 amperes and 20,000 volts inverse peak.

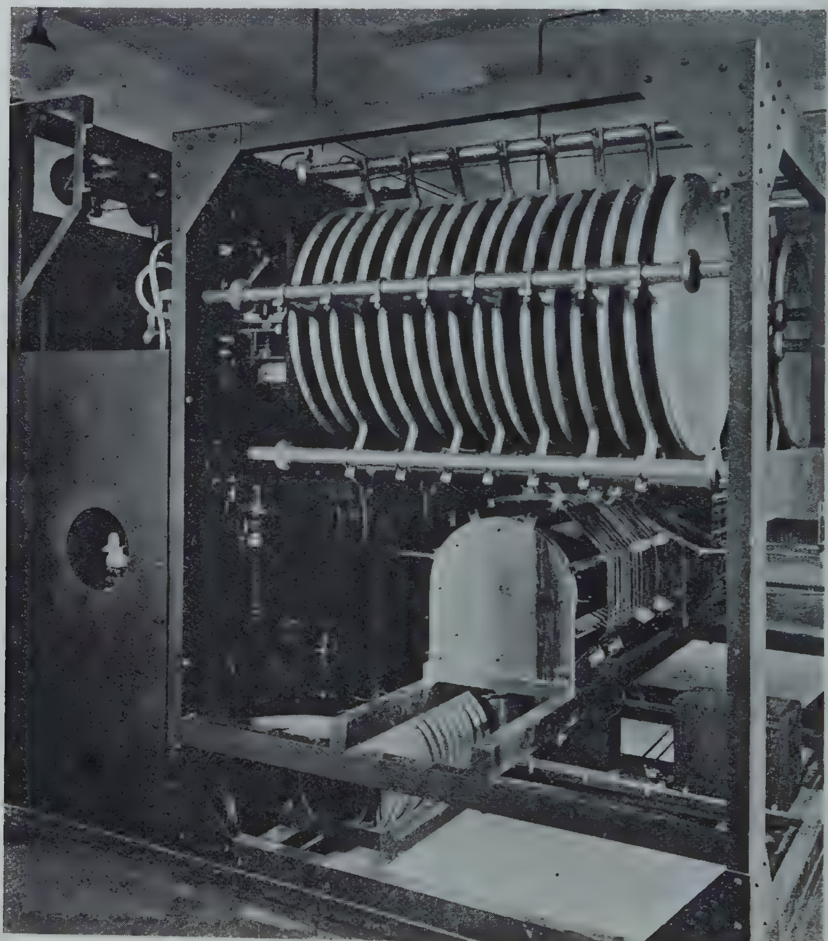


Fig. 33—Side view of power amplifier.

The screen-grid transmitting tubes which allow high amplification without the necessity of neutralizing have also aided greatly in the perfection of this transmitter.

The 50-kw transmitter may be roughly subdivided into a 5-kw modulated exciter unit consisting of the radio frequency units of the

5-kw class B transmitter previously described and a 50-kw power amplifier. In this application the rectifier usually supplied with the 5-kw transmitter is omitted and power for the 5-kw amplifier is obtained from the main power rectifier which also supplies the 50-kw power amplifier. The 50-kw class B transmitter is a complete unit operating from a three-phase, 2300-volt power supply and an audio input of approximately -10 db, to deliver 50 kw of completely modulated output at the antenna.

The modulated exciter unit has been fully covered since it is identical to the corresponding units of the 5-kw class B transmitter.

The 50-kw amplifier mounts 2 UV-862 power amplifier tubes with their associated tuned grid and plate circuits. It also contains the monitoring rectifier by means of which the quality of transmission can be checked either visually or through the regular monitoring loud-speaker system. The UV-862's may be seen in their jackets, (Figs. 32 and 33) behind the doors at the sides of the front panel. The grid circuit of the 50-kw power amplifier is tuned to facilitate coupling and control. The UV-862, 100-kw tubes are operated in a balanced circuit. Their output is 50 kw under conditions of no modulation. Under conditions of complete modulation their output rises to peaks of 200 kw. The plate tank circuit for this stage consists of a suitable air condenser and inductance. Air condensers are used in this stage because of their greater dependability in high powered circuits. They are unaffected by flash-overs or voltage surges which might be the result of misadjustment and which could require the temporary shutdown of an amplifier equipped with mica condensers. They are also more economical for this application. Coupled to the tank inductance is the transmission line coupling coil and also a pickup coil for the monitoring rectifier.

The UV-862's in this stage operate at 18,000 volts plate potential. A grid bias of approximately 360 volts is necessary. Tubes operate at an efficiency of approximately 35 per cent during periods of no modulation and this efficiency rises to approximately 70 per cent during peaks of complete modulation. It can be seen, therefore, that the average power drawn from the plate supply rectifier is about 143 kw to this stage. The filaments of the 100-kw tubes require 207 amperes at 33 volts. The result of cooling water failure is evident and particular attention has been given to water-flow protection which makes the application of either filament or plate voltage to the tubes impossible when the water supply is not available. An air blower supplies a jet of cold air which is fed in at the top of the tube water jacket on the glass-to-anode seal. Another jet of air is supplied to the filament

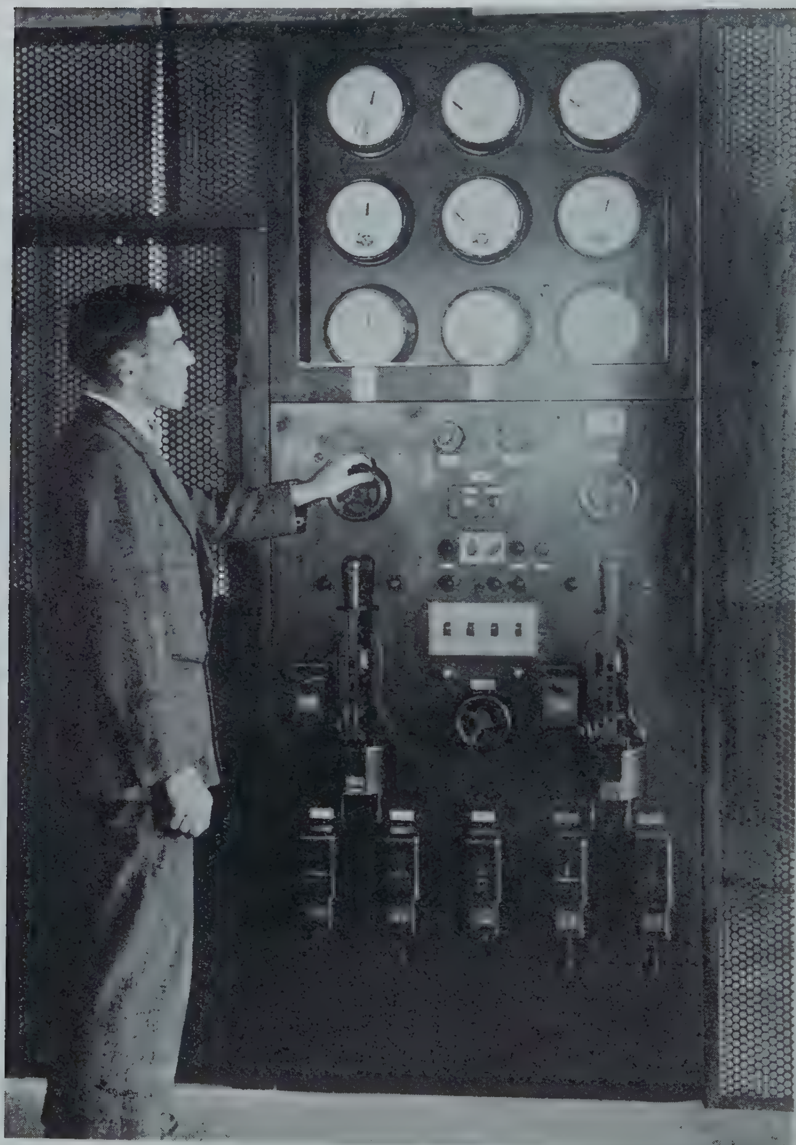


Fig. 34—Front view of control panel.

press. The supply of cooling air and water is applied to the tubes for a period of 15 minutes after the transmitter has been shut down to insure slow cooling.

Power Control Panel

The power control panel, Fig. 34, contains the equipment for switching, metering, and adjusting the outputs of the main high voltage rectifier unit and the filament and bias rotating machinery.

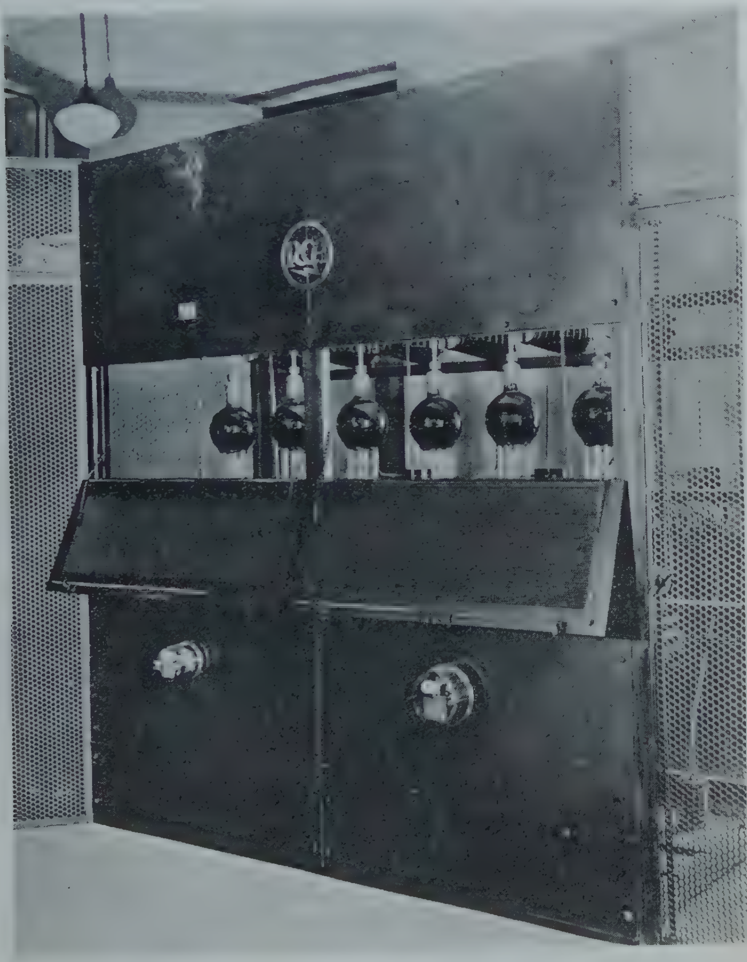


Fig. 35—Main rectifier, 50-kw broadcast transmitter.

Indicating and recording meters on this panel allow the operator to keep a constant check of conditions in the transmitter. A push-button control station on this panel makes it possible to start or stop the transmitter from this point.

High Voltage Rectifier

The unit shown by Fig. 35 mounts tubes and associated equipment for the three-phase, full wave mercury vapor rectifier. This unit also mounts a time delay device for allowing the tube filaments to come to proper temperature before plate voltage is applied. A tube life meter on this unit records the number of hours during which the tubes are operated. Plate transformers, filter condensers, reactors, and other power equipment associated with this unit are mounted elsewhere in the station. An induction voltage regulator controlled from the main power control panel allows a variation of the rectifier output voltage from 50 to 100 per cent normal value. This regulator may be operated manually or automatically as desired. A voltage reducing unit consisting of a resistor bank with the necessary by-pass capacitors lowers the output voltage of this rectifier to a suitable value for operating the UV-863 tubes in the 5-kw class B intermediate amplifier.

Cooling System

The cooling system is of the closed type in which distilled water is circulated through the tube jackets and then through an external cooling unit from which it is returned to a storage tank. It is fully interlocked, and electrically operated valves control the drainage of the system to protect against freezing during periods of shutdown.

Antenna Equipment

The transmission line is so terminated in a resonant circuit that a minimum of harmonic voltage is induced in the antenna system. This resonant circuit together with the necessary inductances and capacitors for balancing the transmission line and operating the antenna correctly are supplied as a part of the transmitter.

Operations and Controls

The 50-kw transmitter is controlled from an operator's control box in the same manner as the 5-kw transmitter previously descirbed. It is fully automatic and can be started from a single push button.

Performance Characteristics

The performance characteristics of the 50-kw class B transmitter are practically identical with those described in connection with the 5-kw class B transmitter.

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THE RCA PHOTOPHONE SYSTEM OF SOUND RECORDING AND REPRODUCTION FOR SOUND MOTION PICTURES*

By

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Summary—*The general considerations governing the selection of a sound-on-film recording and reproducing system are analyzed, and the variable width track for recording and the dynamic cone with directional baffle for reproduction are described as best suited for studio and theater applications.*

The recorders, sound heads for projectors, amplifiers, switching and control devices, power supply, and loud-speaker systems of various types of RCA Photophone equipment, are described in detail.

THE research engineers of the General Electric Company and the Westinghouse Electric and Manufacturing Company, being aware about ten years ago of the probable value to the theatrical industry of an effective system of sound motion picture production, initiated fundamental researches which have been carried forward to the point of fully meeting the aims of these investigators. The resulting basic methods, suitably developed, and tested by extensive commercial experience in the studio recording and theater reproducing installations of RCA Photophone, Inc., form a complete and modern system which is at present widely used in the sound motion picture industry. During the last two years the engineers of RCA Photophone have been responsible for the general specifications and operating adequacy of the designs, as well as for the application engineering of the equipment in question, and it is believed that they have thus contributed substantially to the quality of the resulting products.

The authors desire at this point to express their appreciation of the original and painstaking work of the research engineers of the two manufacturing companies mentioned above, and particularly since the basic principles which these workers had selected and rendered available have proved to be fundamentally correct and eminently suitable for wide commercial application.

The entire development of the RCA Photophone system has been distinguished by a rather unusual circumstance: to wit, that strict adherence throughout the research and development stages was given to two guiding principles; namely, that sound reproduction cannot

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be *too* accurate, and that, under all circumstances, "the show must go on." It is somewhat rare for research laboratory workers to place adequate stress on these important practical points since the obtaining of an interesting and instructive result, rather than an entirely practicable one, is the more usual objective in the laboratory. The requirement of high reliability of operation in commercial installations is one which frequently fails to receive adequate attention even in commercial engineering development groups (not to mention among research workers).

The high quality of sound reproduction of even the earliest theatrical sound motion picture equipment of RCA Photophone was a source of somewhat rueful satisfaction to the executives of that organization for a reason which is now readily comprehensible. Early sound recording from certain sources left much to be desired as regards its fidelity. Tones of low frequency were missing and tones of high frequency were similarly conspicuous by their absence. Studio resonance, incorrect photographic exposure and development of variable density sound tracks, and amazingly dirty or injured sound tracks all combined to produce a record of intrinsically poor quality. When such a record was played on a rather poor reproducing apparatus, the acoustic characteristics of which were also bad, it sounded about as might be expected, and yet but little worse than a good record played on the same equipment. When played on a high quality reproducing outfit, the defects of poor records were glaringly displayed and the listener, frequently unacquainted with the cause of the poor reproduction, blamed it on the reproducing equipment. In this instance, as in certain other fields of unusually complicated character, high ideals of performance lead to temporary difficulties though it is generally possible to overcome them in time as the art develops closer to the selected ideals.

In the design of the equipment of RCA Photophone, conditions in the theater were carefully studied through years of experimental work and investigation, and also through contact with exhibitors of wide experience. The design of recording equipment was guided by similar information secured from producers and from practical studio directors and managers.

A fundamental point in the design of the theater equipment, and one which received too little attention in the earlier days of the sound motion picture, was the amount of audio power required for theaters of various sizes. The exact amount of power is, of course, a complicated function of local conditions, depending on the size and dimensions of the theater, the acoustic characteristics of the walls, floor, and ceil-

ing of the theater, and of any other acoustic absorbing material (including the audience), the percentage of the maximum audience present, the excellence of the loud-speaker system, its effective directional characteristic, and certain other factors. For example, full consideration must be given to the effect produced on speech from the vaudeville actor by acoustic treatment to reduce reverberation. In efforts to retain the quality of speech in sound motion pictures, it is not difficult to reach a point where the acoustic damping of the house, and the resulting sound absorption are so high that the speaking actor labors under a serious disadvantage and fails to "get across." This subject has engaged considerable attention among practical managers of theater circuits.

The necessity for high quality and reliable service are obvious when one considers that thousands of people, having paid admission fees at the box office, are seated in a theater supposedly patiently awaiting the resumption of the performance the moment sound equipment fails. For a minute or two they wait with a fair degree of patience (but with a lack of any kindly reaction toward the management); thereafter with an increasing volume of laughter and stamping they give vent to their growing dissatisfaction. Keeping in mind this necessity for quality and service, the "sectional book-case" method of building RCA Photophone equipment has been adopted. In this method of design, duplicate or sectionalized operating units are provided throughout the amplifying and loud-speaker systems, so that a complete failure of any section of the apparatus can result in nothing more than a reduction of sound volume in certain sections of the theater, but will not result in the objectionable feature of a complete stoppage of the performance. By the use of loud-speakers on the stage divided into groups or separate sections, each fed by individual power amplifiers, which in turn are fed by one or the other of a pair of voltage amplifiers, equipment can be produced along the lines of a normal design, with satisfactory continuous operation and at a reasonable cost.

For smaller installations where any duplications of apparatus would introduce an economic handicap, an alternative principle has been adopted, namely, the provision of rapidly and simply removable unit sections. Such a system, in addition to minimizing the length of service interruptions, enables the systematic testing and repair of equipment by removing the defective unit to be corrected at a local service station.

Reliability of operation has also been increased considerably in other ways. There has been little hesitancy in breaking with tradi-

tional methods and equipment for accomplishing certain results in sound recording and reproducing whenever valid justification for a simpler, more effective, or more reliable mechanism was found. For example, it is customary in many theater reproducing outfits to change from one projector to another, so far as sound transfer is concerned, by the use of manually-operated composite fader-and-change-over control. The equipment for this is generally mounted on the front wall of the booth and is either handled by the projectionist walking over to the equipment to make the required change-over, or through a more or less complicated mechanical system of remote control. In the theater reproducing equipment here described, a special design permits the change-over by merely throwing a switch located at either of the respective projectors. Contrary to the views of some, such a simple change-over is silent and feasible.

Among the important factors of sound motion picture reproduction in the theaters is the quality of the recording (which is necessarily limited by the recording method which has been adopted) and the characteristics of the loud-speaker or sound projecting system which has been adopted.

RCA Photophone has been and remains the leading exponent of variable width (or variable area) sound track recording. The sound track is a narrow black area extending parallel to the length of the film, the serrated edge of which corresponds with a high degree of fidelity to the instantaneous portions of the sound wave which is recorded. The sound track, therefore, consists of two portions, a black portion and a white portion, and the shifting boundary shape determines the sound.

As is well-known, the successful photography of subjects which include a wide range of light intensities with numerous variations of tone is a difficult task requiring precise exposure and carefully timed development, using a developer of known concentration and at definite temperature. On the other hand, the development of a mere black-and-white print, without half-tones, is not difficult. Accordingly it has been found that the variable width sound track makes no undue demands for a successful result so far as extreme precision of exposure or unusual care in development are concerned. It may be truthfully said that *the positive with variable width sound track can be developed for the picture alone, without attention to the sound track!*

The type of recording equipment utilized for variable width sound recording does not depend upon extreme variations in the illumination intensity of a light source, or roughly equivalent shutter action in front of a constant light source, but simply upon the normal vibration

of an oscillograph element. The oscillograph is an important and obviously useful device in this connection. It has stood the test of experience in the hands of practical men for nearly a half century, and to such an extent that the oscillograph is now a portion of the standard equipment of every electrical laboratory, and it has long been so. The oscillograph used at present for sound recording stands up well even under the extremely trying conditions of sound-newsreel recording. It is known, however, that the reliability of these devices can be even further increased without injury to their operating characteristics, and to an extent quite beyond the requirements of the motion picture art.

Another factor that contributes toward high quality of reproduction is, as has been mentioned, the loud-speaker system. The loud-speaker is the "neck of the bottle" in sound reproduction. Even if everything in the recording and reproducing process up to this point is well done, the loud-speaker can badly mar the result and deliver sound in a distorted form to a dissatisfied audience. For this reason an unusual amount of care has been taken in the choice of a loud-speaker system for RCA Photophone installations. As the main element in this system, the dynamic cone speaker was chosen. It is an extremely rugged device. It was developed for radio installations in such a fashion as to be free from service defects under quickly varying and sometimes unfavorable conditions of temperature and electrical load. It was known to be free from undue manufacturing difficulties, and capable of duplication on any desired scale.

Its acoustic characteristics enabled it to displace all competing devices in the quality field of radio broadcasting. No difficulty was found in adapting this type of speaker for sound motion picture purposes inasmuch as it proved capable of such flexible modification as might be desired.

Evidently the dimensions of the dynamic cone speaker which correspond to those of the small diaphragm of the older type of horn loud-speaker are the dimensions of the cone itself. Having a considerable area of vibrating surface and direct contact with the air, there is no difficulty in obtaining adequate low frequencies on such a cone speaker and therefore getting a satisfactory low-frequency response. In the case of a small diaphragm, low-frequency loading becomes a problem. The low frequencies (below about 150 cycles) are more important factors in the successful reproduction of the music and speech than is generally known.

At the higher sound frequencies, the dynamic cones have also shown satisfactory capabilities. The intelligibility of speech, the clear,

crisp reproduction of music, and the individual characteristics of certain noises are dependent upon the high-frequency range, and this factor also has received full attention in the speakers which are utilized.

Despite laboratory measurements and curves which are alleged to prove the contrary, through incorrect application of incomplete data, the dynamic cone has proved to be an efficient sound radiator in the theater and to require entirely reasonable amplifier output power for adequate volume of reproduction.

The problem of sound distribution is one which varies from theater to theater, but in general it may be stated that the excessive reflection of sound from the side, top, and rear walls of the theater is frequently responsible for mutilated speech in some parts of the audience. To avoid this necessarily involves a means for directing the sound into certain zones in the theater, generally towards the center of the house. For this purpose there was developed a directional baffle (capable of application to an individual cone or assembly of cones). The device as used introduces no resonances and none of the "tinniness" of the so-called "horn action" which was characteristic of some earlier attempts to utilize horns for theater loud-speakers. On the contrary, the directional baffle is free of some of the defects of the above so far as sound reproduction is concerned but functions practically and effectively as a directional and loading device exclusively, and usually even improves the acoustic characteristics of a dynamic cone loud-speaker to which it is attached. In other words, the directional baffle really betters the reproduction and smooths the loud-speaker characteristic, and is therefore regarded as a distinct contribution to faithful reproduction of sound in theaters. It also prevents backstage radiation with its accompanying disagreeable, boomy, and unintelligible reproduction. In the equipment for large theaters it permits the use of a number of groups of directional loud-speakers so that any normal distribution of sound can be obtained throughout the house. We shall give below certain data relative to the specification and performance of such loud-speaker systems, from which it will be evident that they represent a marked advance in the art of sound reproduction over previously existing devices.*

Elements of a Reproducing System

The elements making up a complete reproducing system are usually as follows:

1. Stage speakers
2. Amplifiers

* See also L. Malter, "Loud-speakers and theater sound reproduction," *Jour. Soc. Motion Picture Engineers*, June, 1930.

3. Control and switching system
4. Film and disk record (reproducers)
5. Booth monitor speaker
6. Signaling system
7. Power supply

A brief discussion of the functioning of these elements and a short description of the RCA Photophone designs of each will follow.

Speakers

The ultimate goal in theater reproduction in sound motion pictures is the complete and absolute simulation in the theater of the original sound impinging upon the sound pickup. If any distortion is desired for "artistic reasons," it must be deliberately introduced and controlled but not be inevitably present. Up to the present time the recordings available have not been sufficiently uniform in their characteristics, to permit satisfactory reproduction when the reproducing system including the loud-speaker, possessed ability to amplify the entire range of musical frequencies uniformly. If most of the recordings available up to this time are reproduced on such a system, speech is very unnatural and boomy. Considerable improvement has been made in recording during the last few months, so that it may be possible within a short time to take full advantage of the capabilities of the best type of speakers available.

If the sound is recorded so that all frequencies are recorded with the same efficiency, perhaps the most important characteristic of a loud-speaker is that of response for the various frequencies comprising the musical and speech spectrum. The speaker should not cause distortion due to a non-linear response as the amplitude changes since this would cause harmonics. For use in large auditoriums it is desirable for the speaker to have a fairly directional characteristic as had been pointed out above.

In Fig. 1 is shown the frequency characteristic of the cone type speaker with a directional baffle. The speaker assembly is illustrated in Fig. 2. The dotted curve shows the comparative response of one of the best air-column speakers using a small metallic diaphragm. It should be noted that the air-column speaker is deficient in its response below 500 cycles as compared to the range from 500 to 5000 cycles. The directional effect of the cone speaker with the directional baffle is approximately the same as for the air-column speaker.

For the accurate reproduction of music it is absolutely essential that the frequency range extend well below 100 cycles. In theaters which are satisfactory acoustically, and with faithful recording, full

advantage can be taken of the superior characteristics of the speaker having good response at low frequencies. In reverberant houses it is

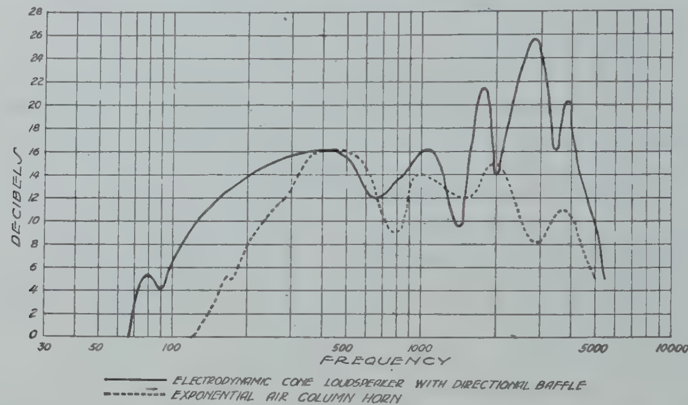

Fig. 1—Relative frequency characteristics of dynamic cone and horn loud-speaker.

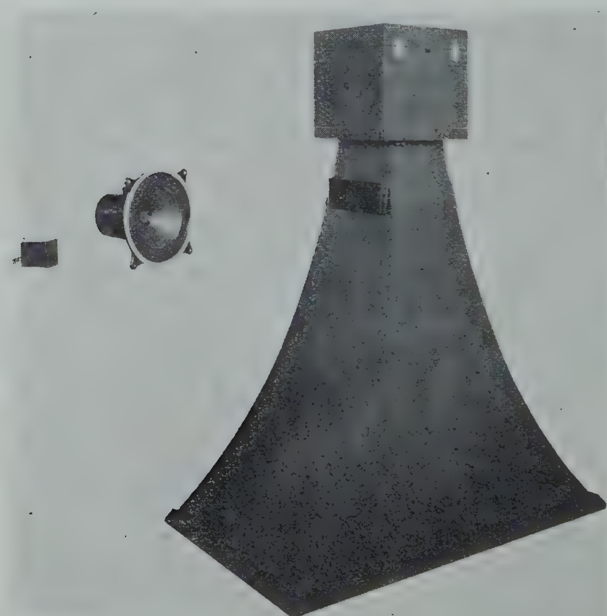

Fig. 2—RCA Photophone cone loud-speaker with directional baffle, broken down for shipment.

not always possible to take advantage of its superior performance because the directional radiation characteristics of speakers are less pronounced as the frequency is decreased.

The number of speakers used in an installation depends upon the width of the house and the arrangement of the balconies, and upon the size of the house.

Amplifiers

Taking into consideration the efficiency of the speakers, experience has shown that the general range of power required from the amplifiers to deliver sufficient volume for satisfactory reproduction of speech and music is from 8 to 200 watts. Amplifiers having an undistorted power output of 8 watts appear to have sufficient power for average houses up to about 1000 seats. This power is more than ample for speech but may not be sufficient for music when the fidelity to be obtained is such that the reproduction to be obtained is more nearly equal to the original music. The low frequency instruments require

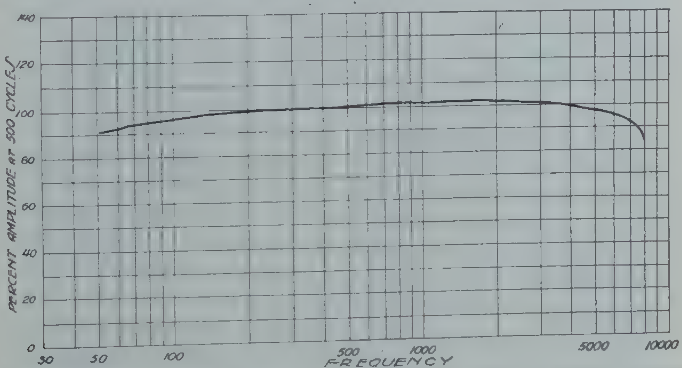

Fig. 3—Characteristics of representative RCA Photophone amplifier.

considerable power capabilities for faithful reproduction. Fig. 3 shows a typical over-all characteristic for a four-stage RCA Photophone amplifier.

The largest type of amplifier is illustrated in Fig. 4. There are two complete amplifiers arranged so that either amplifier may be used at will by means of convenient change-over switches. As these amplifiers are used in the largest theaters, delays would disappoint a large audience and the insurance against breakdown secured through the use of duplicate amplifiers is warranted.

Each amplifier unit consists of a power amplifier panel, voltage amplifier panel, input panel, indicator panel, and control panel. A speaker switching panel is provided on one amplifier rack.

The maximum power output of the power amplifier panels is approximately 200 watts. These panels each have 10 UV-845 Radiotrons connected in parallel push-pull.

The voltage amplifier panel consists of three stages using UX-210 Radiotrons in the first and last stages and a UX-841 in the second stage. The amplification is controlled by means of a voltage divider in the grid circuit of the second-stage amplifier.

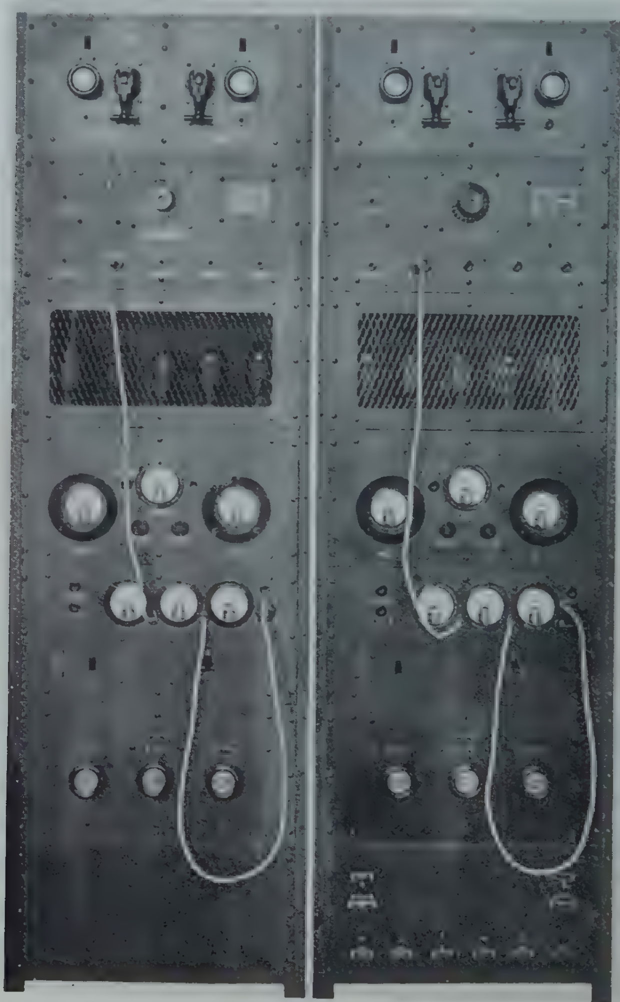

Fig. 4—Amplifiers, including loud-speaker switching panel.

On the input panel is provided current controls for lamps in the sound-on-film machines.

The indicator panel is provided with jacks and instruments for measuring the various voltages. The filament, plate and bias voltages

for the power amplifier, and current for film reproducer lamps and speaker fields, are supplied from a motor-generator set, a separate

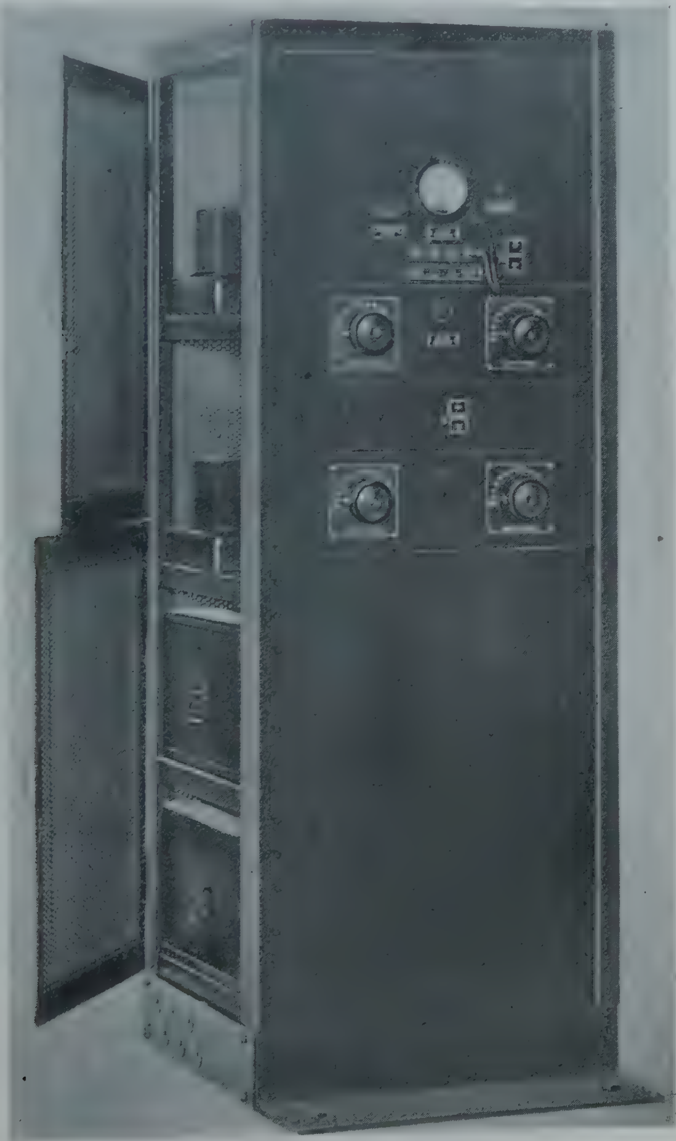

Fig. 5a—Voltage amplifier.

unit being provided for each panel. B batteries furnish plate current to other tubes and to the photo-cells.

The input transformer of the voltage amplifier is designed to work from a 3500-ohm circuit, which is found suitable for minimizing the effect of capacity in the photo-cell leads.

Fig. 5b—Power amplifier.

The next size of amplifier is illustrated in Fig. 5. The power amplifiers are mounted in a rack (Fig. 5a) separate from the voltage ampli-

fiers. The power amplifier rack contains two power amplifier control panels, one master power input control panel, one filter panel, and four power amplifiers mounted on shelves behind these panels. Suitable terminal boards are provided for incoming and outgoing cable connections. Terminal strips, provided with screw terminals and plug connectors, serve for all connections to the individual power amplifiers. This arrangement provides for easy and quick removal of the amplifiers for inspection and service. Each power amplifier is complete with its own power supply from the commercial power system. The construction is similar to that of present-day power units of a-c operated radio receivers. The filaments of the two UX-250 Radiotrons are heated by alternating current and the plate power is supplied by a full-wave rectifier using two UX-281 Radiotrons.

The power amplifier has an input transformer feeding two UX-250 tubes in push-pull. The transformer is designed to work from a 500-ohm circuit, which is a suitably low impedance to permit of the necessary runs without unduly attenuating high frequencies, and reduces certain otherwise possible regeneration. The output transformer is designed to connect directly to the speakers, the fields of which are supplied from a Rectox (dry contact rectifier) unit mounted on the same base and connected to a winding on the same power transformer which operates the UX-281 rectifiers. Each amplifier has two UX-250 tubes in push-pull and has an output of approximately 10 watts. The total power output of this amplifier is approximately 40 watts.

The voltage amplifier rack contains two voltage amplifier control panels, one metering panel, and one switching panel. On shelves behind the panels are mounted two voltage amplifiers and two battery boxes. Suitable terminal boards are provided for external connections to the rack. Convenient screw type terminals are placed on the amplifier units to facilitate removal for service.

Each voltage amplifier has three stages of push-pull amplification using UX-210 tubes throughout. The plate voltage of the tubes is supplied from a 135-volt dry-battery source. The grid bias is supplied by two $4\frac{1}{2}$-volt C batteries. The filament voltage supply is obtained from a 12-volt storage battery through suitable resistors. Each voltage amplifier has an independent control panel. Each panel consists of a volume control, output fader, and indicating lamp to show when it is in use.

The volume control consists of a voltage divider in the grid circuit of the second stage. The output fader is used to decrease the output of the voltage amplifiers in case it is desired to change amplifiers during operation, thus preventing any disturbance from reaching the

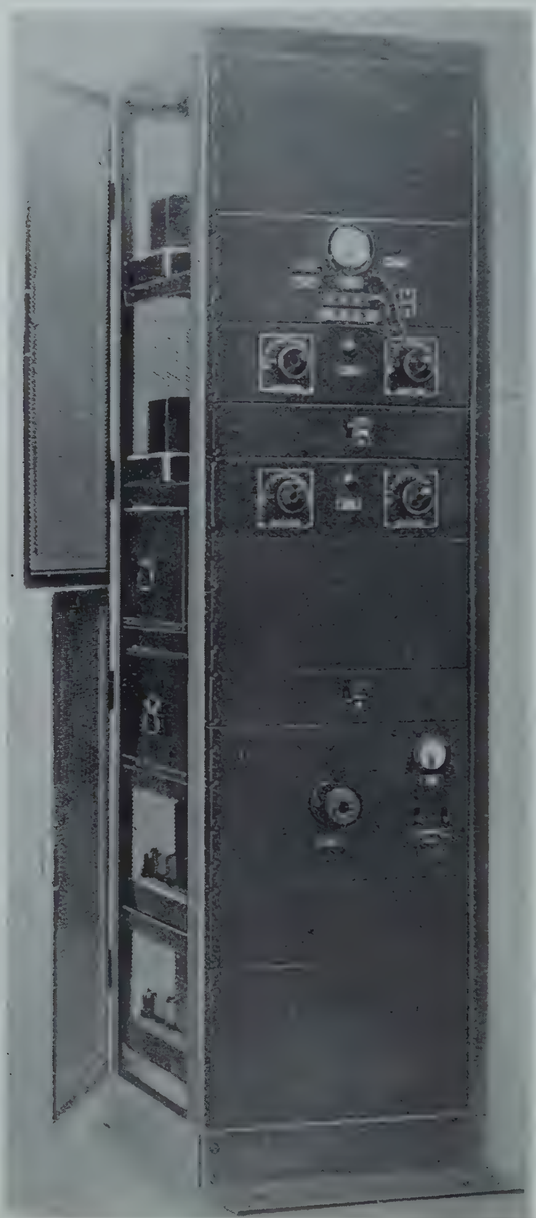

Fig. 6—Amplifier.

speakers. The switching panel has change-over switches for power to filaments and input and output circuits. The metering panel is provided with a multi-range voltmeter and plug. Jacks are arranged so that the battery voltages can be checked. The input of the voltage

Fig. 7—Amplifier.

amplifier is designed to work from a 3500-ohm circuit. The output impedance should be 500 ohms.

This type of amplifier having duplicate voltage amplifiers with push-pull stages and having the power amplifier subdivided into four parallel units, each complete with its power supply, seems to be an

ideal arrangement for insuring against interruptions. Neither the failure of a single tube, nor the failure of one or even more of the power amplifiers, can interrupt the program. If a voltage amplifier unit should fail, the program would be stopped only for the time required to switch to the other voltage amplifier unit. The push-pull stages assist in obtaining excellent amplifier characteristics because of the great reduction in magnetization of the transformer cores. Transformer coupling is employed throughout.

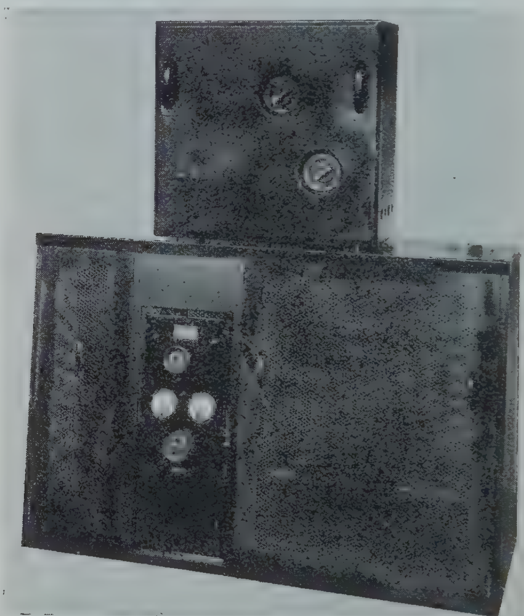

Fig. 8—Amplifier, motor-generator set, and control panel. View showing relative arrangement and enclosures in place.

A filter panel is provided for the purpose of altering the characteristics to compensate for uneven recording. It is often necessary to have a characteristic in the amplifier or speakers that causes the overall output from amplifier and speaker to drop off rapidly below 500 cycles to eliminate boomy speech.

Some recording has "fuzzy" high frequencies and a high ground-noise level necessitating a high frequency cut-off to obtain the most satisfactory results. It is hoped that these conditions will soon disappear so there will be no further need for sacrificing the fidelity, as is sometimes necessary under present-day conditions.

The amplifier illustrated in Fig. 6 is the same in principle as the

type just described except that there are only two power amplifiers and both the voltage amplifiers with batteries and the power amplifiers are mounted in one rack. All amplifier units and component parts are identical.

The amplifier illustrated in Fig. 7 is the same as the two just described except that only one voltage and power amplifier are provided. The amplifier units are the same as for the other types. A change-over relay for switching from one projector to the other at the end of each reel is mounted on one of the panels.

Fig. 9

Another amplifier, which has been designed for smaller theaters, is a single unit four-stage amplifier having a push-pull power stage using UX-250 Radiotrons. A single wall-mounted cabinet houses both the amplifier and filter system for the plate power supply. The power is furnished by a three-unit motor-generator set. The amplifier is transformer-coupled with single tubes of the UX-112A type in each voltage-amplifier stage. The plate supply is fed through a reactor or resistor in parallel to the transformer primary, the transformer primary being coupled through a capacitor to the plates of the tubes.

The volume control is mounted on the amplifier unit. A compensator or frequency control is mounted on the filter unit. The controls are shown in the illustration Fig. 8. In this photograph the amplifier

is shown mounted on top of the motor-generator housing. Fig. 9 shows the amplifier and filter housing with the front removed. A change-over relay is mounted on the same base as the filter system, as well as two signal lamps to indicate which projector is connected to the amplifiers. All connections are made through screw-type terminals for ease in servicing.

The motor-generator set furnishes power for the speaker field and lamps in film reproducers as well as for the amplifier. A filter system is mounted in the motor-generator set housing for the low voltage supply

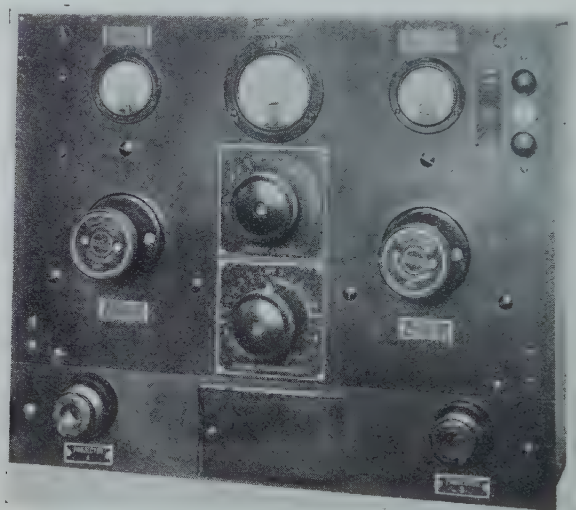

Fig. 10—Front view of input control.

for filaments, exciter lamps, and speaker field. The only batteries used are two small dry batteries for grid bias. Because of the elimination of batteries and simple wiring in the booth, the installation expense is kept low.

Control Circuits

Arrangements for switching the input of the amplifier from one machine to another, for changing from film to disk pickup and for equalizing the voltage from disk record and film pickup are essentially the same for all equipments.

The output circuits from either disk or film are arranged to work into the 3500-ohm input circuit of the voltage amplifiers.

A control panel used with three of the amplifiers is shown in Fig. 10. There are two rheostats for controlling the current to the exciter lamps and ammeters for reading the value of the lamp current.

A change-over potentiometer is provided for switching the amplifier to either machine. If more than one change-over control is desired, mechanically connected extensions are provided or a relay system is installed which can be controlled from either machine.

Film and Disk Reproducers

Fig. 11 shows a film reproducer as used with the control panel described above. The illustration shows the mechanism mounted on a Simplex projector. The projector is driven by a synchronous motor at

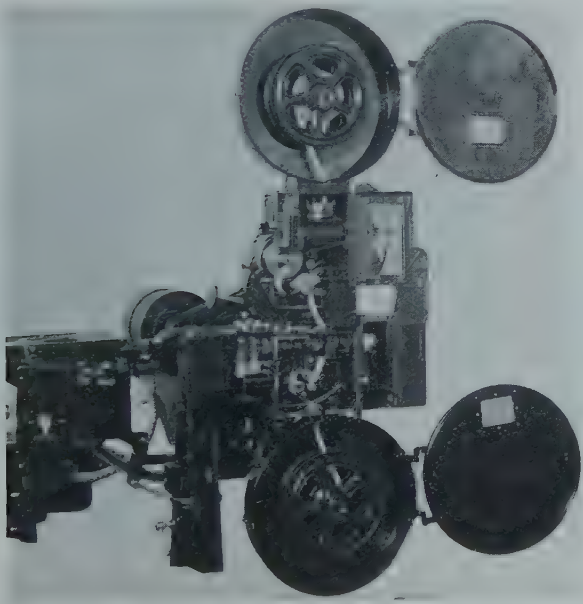

Fig. 11—Sound reproducer and synchronous disk attachment for type S Simplex projector.

a speed which runs 90 feet of film per minute. The sprocket which pulls the film past the scanning light beam is mounted on the same shaft with a flywheel. This assembly is driven through a very flexible spring. A brake in the form of a greased leather pad acts as a viscous brake on the flywheel to prevent oscillations of the spring-driven system. A holdback sprocket is provided to prevent the take-up tension on the film from affecting the tension of the constant speed sprocket.

The gate, for guiding the film and holding it in focus at the scanning light beam, consists of a set of standard Simplex lateral guide rollers mounted at the top of a curved shoe and a pair of flexible springs

mounted so that they hold the film in contact with the polished surface of the shoe. The curved shoe prevents the film from buckling and running out of focus, and is a desirable feature.

Three lamps for the scanning light are mounted in sockets on a revolving turret. Each lamp can be pre-adjusted in position so that if one should burn out it is only necessary to turn the next one into position, thus minimizing the interruption caused by the lamp burning out.

The lens system consists of a condenser lens so placed as to concentrate a miximum amount of light on a slit 4 mils wide mounted in the enclosure of the cylindrical barrel. An objective lens system focuses an image of the slit 1 mil wide on the emulsion side of the film. The

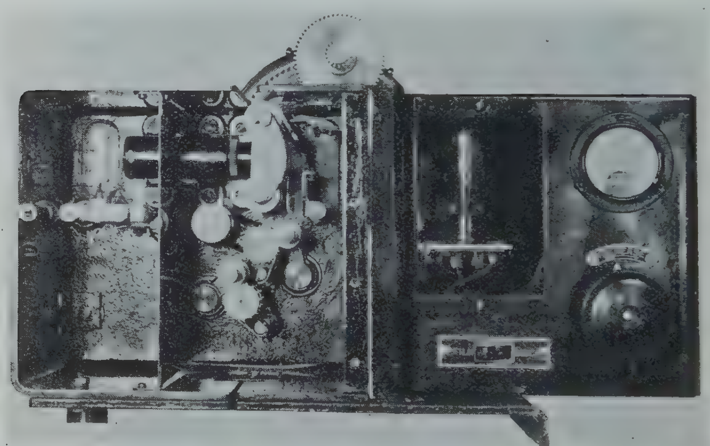

Fig. 12—RCA Photophone sound head.

light passes through the film to the photo-electric cell in the box at the front of the machine. The entire lens and lamp assembly is adjustable for focusing and aligning the scanning beam on the film.

A transformer is mounted in the box with the photo-cell and adapts the output to a 3500-ohm circuit which can be run to the control panel or amplifier without appreciable loss of high frequencies caused by the capacity of the circuit. When the control panel is omitted, the rheostat and meter for the scanning or exciter lamp are mounted in the photo-cell box as show in Fig. 12.

A less expensive and simplified type of sound-on-film reproducer is shown in Fig. 12. In this device the sprocket pulling the film through the scanning gate is driven directly through precision gearing, and filtering action is obtained by having the film drive a flywheel by means

of a roller located just below the scanning gate. In this machine the lens assembly is not adjustable but the focusing adjustment is taken care of by an adjustment of the objective lens. The scanning line is located on the film by an adjustment of the lateral guide rollers at the top of the gate. The two lamps are adjusted in position in the holders and it is only necessary to pull one holder out and insert another in case of a lamp burning out.

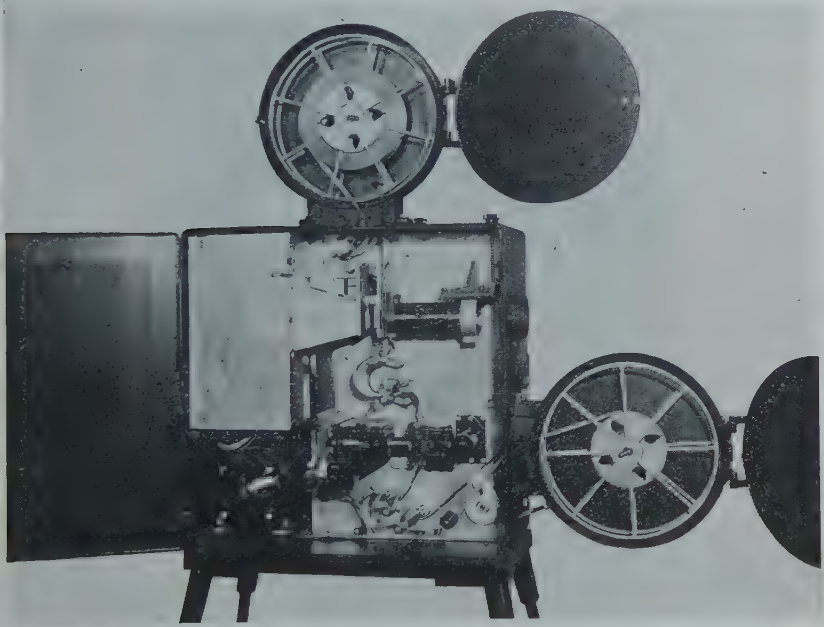

Fig. 13—Film driving side of RCA Photophone portable sound picture projector. Note travel of the film from the upper film magazine, through the picture projector mechanism, sound reproduction mechanism, and into the lower take-up magazine. The sound reproducing system is identical in detail with that supplied in the theater equipments of RCA Photophone. The opposite side of the projector contains the drive shafts, gearing mechanism, etc., for operating the device.

Semi-portable Reproducing Equipment

For use in clubs, schools, and viewing rooms, and for "road-showing" sound pictures in places where there are no sound installations, a semiportable equipment has been developed.

The projector shown in Fig. 13 is a self-contained unit, consisting of the lamp housing, picture projector, motor, and all the parts of a standard sound-on-film reproducer. The film magazines are remov-

able so that the projector case fits in a trunk designed to protect the projector adequately during shipment.

In order that all batteries shall be dispensed with, an exciter lamp with a 27-volt, 1-ampere filament is used. The power for this lamp is supplied from a dry-contact rectifier mounted in the amplifier case.

The lamp for the picture projector may be a standard 600- or 1000-watt lamp. Switches for the picture lamp and projector motor are mounted on the back of the case. Projector stands with adjustable legs are provided.

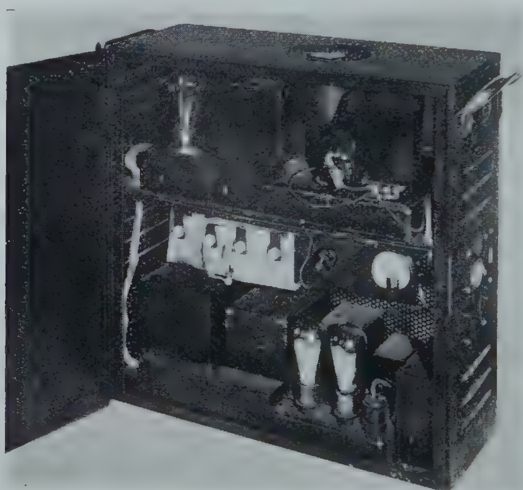

Fig. 14—View of the RCA Photophone portable sound picture system amplifier. This contains the necessary tubes for amplification of the photo-electric cell current in the projector. The system also contains rectifier units to supply the necessary direct currents needed in the operation of the equipment. The amplifier is connected to a source of 110 volts a-c, 60 cycles. All connections are made by non-interchangeable plugs, guarding against possible error in connections.

The single control on the top of the unit is the volume control knob graded in steps of 2 TU. At the right, on the side of the amplifier underneath the handle are located the connection jacks to the projectors, and the small switch for fading over from one projector to a second in the event two projectors are used.

The amplifier has three stages. The first stage is a UY-224 screen-grid Radiotron, the second a UY-227, and the output stage is a single UX-250. UX-281 rectifiers supply power for the plate, grid bias, and photo-electric cells. The amplifier and rectifier for exciter lamps is shown in Fig. 14. A volume control is mounted on top of the amplifier case. The change-over switch is mounted on the amplifier case for making change-overs at the end of reels.

In order that the speaker may be packed in a small trunk, the direc-

tive baffle is made in sections. The sections telescope, and the entire assembly fits in the small trunk shown in Fig. 15. Fig. 16 is a view of the speaker set up in operating condition. A rectifier of the dry con-

Fig. 15—Loud-speaker, complete in trunk.

Fig. 16—Loud-speaker in operating position, rear view.

tact type is mounted on the frame of the dynamic cone speaker for field supply.

A collapsible frame for the screen is provided, its size being 89 by 110 inches. Several types can be supplied, depending upon the

requirements of the user. The screen and frame are packed for shipment in a trunk as shown in Fig. 17. Fig. 18 shows the screen and the complete equipment as set up. Fig. 19 shows the spare parts trunk;

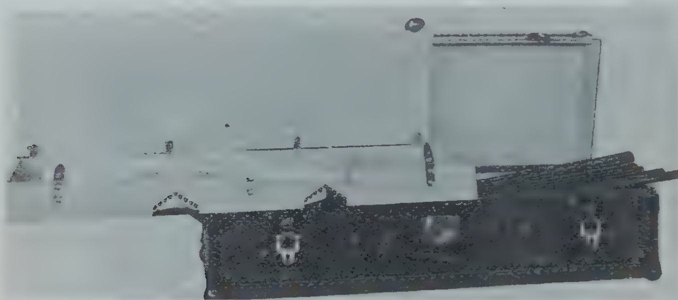

Fig. 17—Screen, screen frame, and trunk used with RCA portable Photophone equipment.

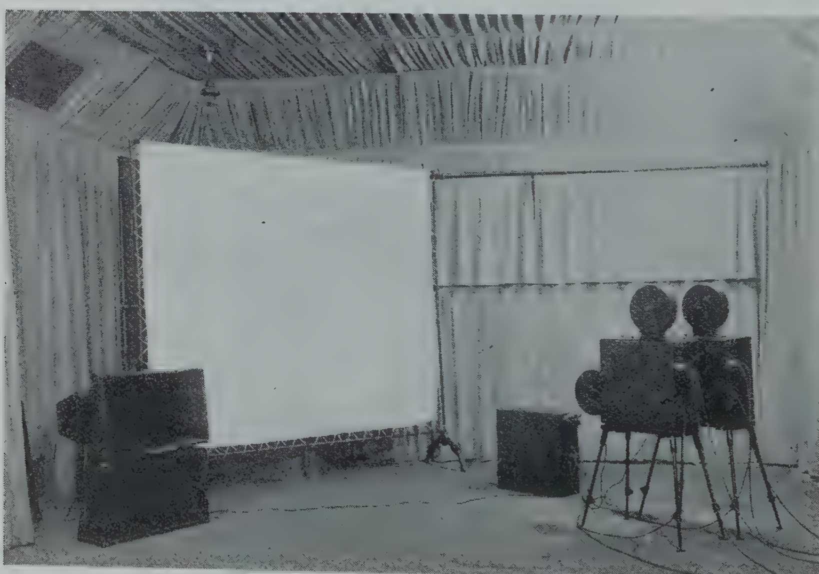

Fig. 18—Portable RCA Photophone equipment set up for operation.

this contains tubes, lamps, film rewinder, splicer, and convenient tool kit.

With a 1000-watt lamp, the semi-portable equipment is capable of projecting a picture 7 by 9 feet at a distance of 75 feet. The equipment has sufficient sound volume for an audience of several hundred people.

Recording Equipment

Recording equipment for sound motion picture work consists of microphones, microphone mixing panels, amplifiers, monitoring means, and a recording instrument.

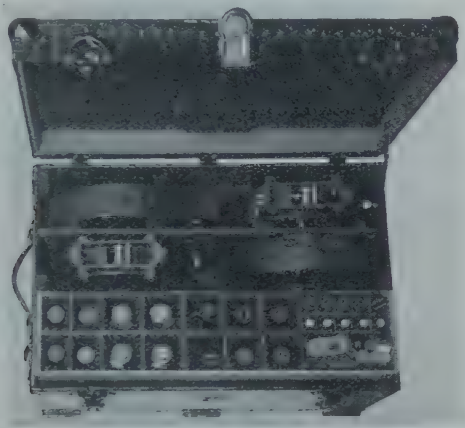

Fig. 19—Accessories trunk for portable RCA Photophone equipment.

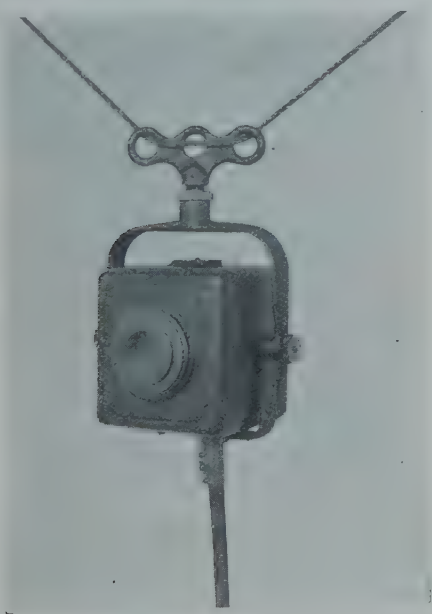

Fig. 20—Condenser microphone installed in microphone amplifier and suspended, using universal mounting.

The microphones used are usually of the condenser type, similar to those used in broadcast studios. Motion picture studios require more rugged designs than broadcast studios as the service is harder

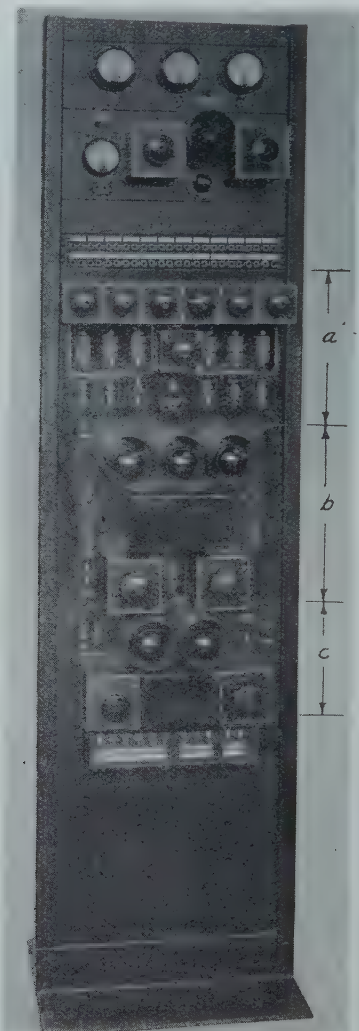

Fig. 21—Photophone recorder amplifier.

The microphones must be kept out of the field of the camera lenses and are therefore usually hung above the heads of the actors or hidden in some object in the set. Fig. 20 shows a typical microphone and associated amplifier arrangement.

The output of the microphone amplifier goes to a mixing panel as shown at (*a*) in Fig. 21. This picture illustrates an amplifier and control panels as used in rack type equipments. The recorder amplifier panel is shown at (*b*), and (*c*) is the monitor amplifier which operates a dynamic cone speaker for studio recording.

The film recording instrument is shown in Fig. 22. This recorder is driven through a spring system by a synchronous motor which is fed from the same power system as the synchronous motor driving the

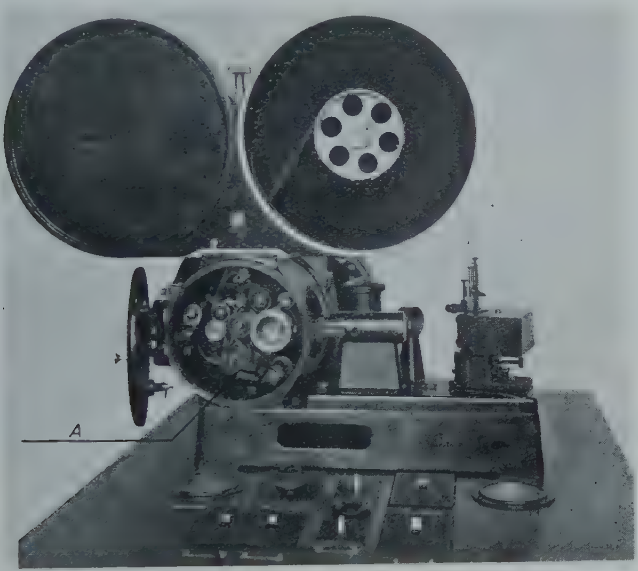

Fig. 22—Film threaded through recorder.

cameras. Film of a suitable type is fed past the recording light line at the desired speed by a smooth drum which runs at constant velocity, thus eliminating all uneven motion which would occur if the film were driven by toothed sprockets. As the film is pulled from the magazines by a sprocket at a definite number of *perforations* per minute, and the drum feeds a definite number of *feet* per minute, it is necessary to make use of an automatic compensating means to maintain the necessary loops between the driven drum and the sprockets for film that has shrunk in varying amounts.

The arm shown at (*a*) in Fig. 22 moves when the loop in the film changes length and this movement speeds up or slows down the speed of the drum. This change is very gradual and causes no perceptible change in pitch when the record is run through a reproducer at constant speed.

The optical system is shown in diagrammatic form in Fig. 23. The spot of light which exposes the film is produced by a small incandescent lamp, a permanent magnet oscillograph vibrator, an arrangement of lenses, and an aperture as shown. As the mirror of the oscillograph vibrates, a vibrating spot of reflected light is focused on the film. The light spot covers more or less of the aperture as it vibrates. In order to aid in obtaining a sharp focus on the film, a viewing screen (VS) is placed between the aperture (A) and the film. This allows the

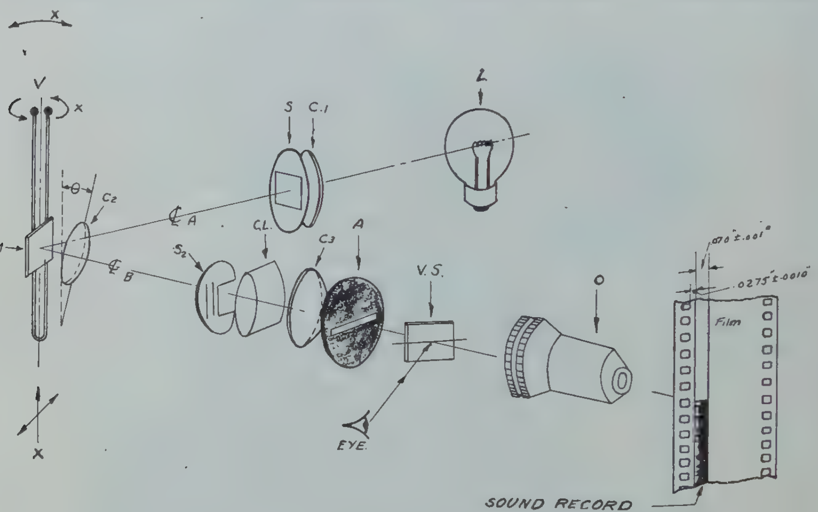

Fig. 23—Galvanometer and optical system.

L Prefocused exposure lamp
C_1 Spherical lens
S_1 Light stop
C_2 Galvanometer lens
V Galvanometer vibrator
M Galvanometer mirror
S_2 Scale
$C. L.$ Cylindrical lens
C_3 Spherical lens
A Aperture
$V. S.$ Viewing screen
O Microscope objective
X Directions of movement for alignment

image on the film to be observed while the objective is moved back and forth during the focusing adjustment.

When properly adjusted, the light covers only one-half of the sound track. This adjustment is checked by observing the spot of light on the scale (SZ). When recording, the spot of light moves back and forth but should not go beyond the outside line on the scale, as this would cause the light beam to "overshoot" the sound track.

The brilliancy of the light striking the film is adjusted to a suitable value by means of a photometer supplied with the recorder. The photometer can be plugged into the recorder drum and the lamp current adjusted. After this calibration of the lamp current, the photometer is removed.

It will be noted that the amplitude of the record with respect to the maximum that can be accommodated on the sound track is observable at all times. This feature, combined with a suitable monitoring speaker for checking frequency balance of music and speech intelligibility, results in a very satisfactory system for checking the actual record being made. The control is considerably more effective than is possible with other recording systems which have been examined and studied.

The recorder is mounted on a table containing the necessary switches and meters. There is a marker lamp so positioned in the recorder that a narrow line exposes the edge of the film when it is lighted. A similar lamp is mounted in the cameras. These lamps are used to mark the films for matching the sound and pictures after they are developed.

Communication between cameramen, director, and recordist is by means of headphones and breast transmitters. In most studios the rack with microphone mixing panel and amplifiers, monitoring speaker, and recorder are all mounted in a portable noiseproof booth which is provided with suitable casters for rolling around the studio to desirable locations where the recordist has a good view of the action. This feature has been found convenient in many instances.

It will be gathered from the foregoing that sound recording and reproduction by the preceding methods are effective in practice and yield commercially valuable results. In other words, the sound motion picture art, as represented in the system which has been described, may be regarded as definitely established as an important part of the theatrical field.

Nevertheless, the authors, as engineers, desire to express their conviction that sound motion pictures (excellent as they are when the best modern practice and apparatus are utilized) leave open a considerable field for expansion of dramatic value, improvement in fidelity and naturalness of reproduction, and refinement in sound recording and reproducing methods. Recording apparatus and technique are accordingly being consistently investigated and improved. Theater equipment is similarly being made even more reliable, accessible, and capable of better over-all performance. Film records are being continually studied in the evolution of methods for producing and maintaining them in a condition which results in a minimum of ground noise and a maximum of realism and dramatic or musical contrast or brilliancy. The highly encouraging results already obtained will be the subject of later papers dealing with such studies and marked improvements in the sound motion picture field.

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THE RADIO COMMUNICATION SERVICES OF THE BRITISH POST OFFICE*

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THE principal services operated by the British Post Office may be broadly classified under the following headings.

I. Ship and shore radio telegraphy operated from stations located around the coast.
II. Long distance, long wave telegraph services operated from the high power station at Rugby.
III. Point-to-point radiotelegraphy services to a number of European countries.
IV. Point-to-point radiotelephony services.
V. Radio telephony to ships.

In addition to these services, as the statutory authority for the control of wireless telegraphy in Great Britain, the British Post Office has a close interest in broadcasting, the control and issue of licences for transmitting and receiving, the investigation of complaints of interference and departure from authorized frequencies in transmitting stations, the approval of types of apparatus for ships' sets and the issue of wireless operators' certificates.

The scope of this paper is a presentation of the main outline of these services with more detailed reference to special features.

Ship and Shore Radiotelegraphy Services

The organization for ship and shore radiotelegraph traffic may be classified into two categories, the long range services and short range coastal services.

Long Range Ship Service.

The long range services are met by the Portishead (transmitting) and Burnham (receiving) stations which succeeded in 1927 a simplex station established at Devizes in 1919.

The Portishead station is of Post Office design and construction. It opened in 1927 with one tuning fork controlled 25-kw transmitter

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and two 6-kw tuning fork controlled transmitters. In 1929 the power of the two latter was increased to 10 kw.

The three aerial systems are supported on four 300-ft. lattice steel masts. Each aerial is a 6-wire cage type built on 6-ft. hexagonal spreaders. The earth system is common to all three transmitters and consists of wires buried over practically the full area of the site.

Power at 400 volts, 3 phase, 50 cycles is taken from the public supply. Main and filament transformers are fed direct from this supply so that rotating machines are required for auxiliary supplies only.

The transmitting plant consists of three tuning fork controlled transmitters fitted with coupled circuits and capable of being adjusted between 100 and 150 kc per sec. Transmitter details are as follows:

Transmitter	No. 1	2	3
Input	25 kw	10 kw	10 kw
Frequency	121 kc/s	149 kc/s	143 kc/s
Main amplifiers	Three 2.5 kw silica	Two 2.5 kw silica	Two 2.5 kw silica
Aerial current	55/60 amperes	35/40 amperes	35/40 amperes

The transmitters are started or stopped and keyed locally or from Burnham, the latter being the normal working arrangement.

The keying relay short-circuits the output from the tuning fork controlled oscillator. With the auxiliary machines running continuously the time occupied in running up a transmitter is 10 seconds.

Subsequent to the completion of the 10-kw sets two short wave transmitters which can communicate with ships in any part of the world have been fitted.

The short wave transmitters operate on 8210 kc per sec. (36.54 meters) and 16840 kc per sec. (17.81 meters). They consist in each case of a single $3\frac{1}{2}$-kw silica valve with a tuned circuit in series with the grid and anode. The type of oscillating circuit in use has been specially developed by the Post Office for this service and has the merit of great simplicity, and with the precautions embodied in the design of automatic compensation for load variation on the alternator supplying the plate voltage, gives a frequency constancy well within the requirements of a mobile service. A 300-cycle supply, rectified and partially smoothed is used, which gives a characteristic 600-cycle note.

The 16840 kc per sec. transmitter is coupled to a horizontal array with a 2-wavelength aperture mounted on a lattice steel girder which is capable of rotation on a vertical axis. Fig. 1 is a photograph of the rotating aerial system.

The rotation of this beam system and the keying of the transmitters are controlled from the receiving station at Burnham. For the 8210-kc-per-sec. transmitter a $\frac{1}{2}$-wave vertical dipole is used as a radiator.

Burnham Receiving Station.

This station is equipped with four receivers with a tuning range of 2000 to 2700 meters and short wave receivers for the 36- and 17-meter services.

The long wave receivers are provided with large frame aerials and verticals providing a cardioid diagram for directional reception, and have six stage high-frequency amplifiers, separate oscillator, and also low-frequency band filters.

A rotating array similar to that at Portishead is provided for directional reception on the 17-meter service.

Fig. 1—Portishead rotating beam.

The use of a beam antenna for reception and transmission gives a substantial improvement on any short wave service, and the use of a rotatable system has solved the problem of adapting the directional array for ship service. After locating a ship by means of the receiving system the transmitting array is directed on the ship by remote control from the receiving station.

Horizontal dipoles with open transmission lines are used for the 36-meter service.

Short Range Coastal Services.

The stations for dealing with the ship and shore coastal services

are situated as follows: Wick, Cullercoats, Mablethorpe (Humber), North Foreland, Niton, Lizard, Lands End, Fishguard, Seaforth, Portpatrick, Malin Head, and Valentia Island. (See Fig. 2.)

The functions of these stations include general public correspondence, ships service, and distress messages, meteorological, navigational, and maritime intelligence.

With the exception of the Lizard, all stations operate on the "nominal" 600-meter wavelength spark or interrupted continuous wave and are, at present, in course of conversion from spark to ICW operation to meet the requirements of the Washington Convention of 1927.

The station at the Lizard is used for the direction finding service and is the only station entirely devoted to this service; the combination of the direction finding and the ordinary ship and shore services at a single station is adopted where the traffic is not too heavy and the stations are suitably sited for direction finding operations. The combined stations are: Wick, Cullercoats, 'Humber', Niton, Portpatrick and Malin Head.

The stations are equipped with the Marconi-Bellini-Tosi system. This apparatus has been found to be very suitable for the dual purpose of direction finding and the reception of short range ship and shore telegraph traffic. The directional properties of the receiver are of great assistance in the avoidance of jamming.

The aerial system is aperiodic and comprises two triangular loops in vertical planes at right angles.

On the completion of the erection of the direction finding plant and, before it is brought into use, the installation is calibrated, by direct visual observation from a special tug which is equipped with a transmitter, on various arcs which may have a radius of from two to twelve miles.

The visual bearings are obtained by means of a theodolite. Where the station is so situated that the vessel is not visible from a point near to the direction finding aerial two theodolite observations are made from suitable points on the coast and the position of the vessel is obtained by triangulation on a chart. Where two theodolites are used the observers are provided with portable receivers so that by listening to the signals passed between the station and the vessel they are able to time their observations correctly. It is the practice to make an annual check of these calibrations.

The stations are not all of equal power but are designed for the particular situation. The nominal power of the stations on the basis of the total power absorbed by the transmitters measured at the ter-

minal of the alternators will be, after reconstruction or completion, as follows:

Wick	3 kw
Cullercoats	1½ "
Humber	" "
North Foreland	" "
Niton	" "
Lands End	6 "
Fishguard	1½ "
Seaforth	" "
Portpatric	" "

In addition, low power emergency transmitters are installed to ensure that the stations will continue to be in commission in the event of the main transmitters being out of action for any reason whatsoever.

In order to avoid mutual interference in congested areas, such as the North Sea, English Channel, and the Atlantic seaboard of the British Isles, a scheme of distribution of frequencies, within the band 390–485 kc per sec. (770–620 meters) allocated for traffic by the Washington Convention, has been agreed with the European Administrations concerned for adoption at the stations in those areas. (Fig. 2.)

In addition, a scheme of distribution of note frequencies within the range of 800 to 1100 periods per second with a minimum separation of 100 periods between flank stations has been adopted for the British stations.

The 'Humber' station is one of those which has already been converted to ICW operation and a description of this station will serve to indicate the general arrangements adopted at the British Radio Stations for the coastal services.

Site and Buildings. The 'Humber' site which is about two acres in extent, is situated at Mablethorpe, Lincolnshire, on land adjoining the seashore. The buildings are of the one-story type and are erected approximately at the center of the site.

Aerial and Earth Systems. The main transmitting aerial is of three-wire "T" type, supported by two tubular masts, 120 ft. high, spaced 246 ft. apart. A separate aerial of 6-wire cage type, approximately 70 ft. long and suspended from one of the masts, is provided for 220-meter telegraphy and telephony.

The direction finding and main receiving aerial system, consisting of two triangular frames of approximately 95-ft. sides and a base 160 ft. long, is rigged beneath the main aerial and is symetrically dis-

Fig. 2.—Map showing British Post Office radio station and ICW distribution of frequencies between coast stations. ·⁑·. Frequencies shown put into operation January 1, 1929.

posed about the other mast. In order to maintain the electrical balance of the two triangular frames, the four lead-in wires from the centers of the base are twisted as in ordinary telephone practice throughout their length to the lead-in panel a distance of 110 ft.

The main earth system is entirely underground and consists of 6- by 2-ft. corrugated iron sheets, buried vertically with their long edges 6 inches below the surface, and arranged in two semicircles of 60 ft. radius, symetrically disposed relative to the main earth point in the building. A separate earth system of similar type to the main system, but consisting of one semicircle of 10 ft. radius, is provided for use in conjunction with the direction finding receiver.

Power Plant. As no public supply is available in Mablethorpe the electrical energy required for the operating and lighting services is generated at the station.

The generating plant comprises duplicate 8-kw engine generators with a secondary cell battery of 56 cells of 300 ampere-hour capacity. Twenty-four secondary cells of 120 ampere-hour capacity are provided for heating the filaments of the receiver valves and for power supply to the emergency transmitter.

Transmitters. The equipment comprises a main $1\frac{1}{2}$-kw coupled circuit valve transmitter equipped for CW and ICW telegraphy, an emergency 100-watt set, and a 500-watt telephony transmitter.

The operation and all control of the transmitters is effected from the operator's position in the operating room; the changes in wave and variations in power are accomplished by a mechanical system of remote control.

Main Transmitter. The rectified high tension supply is from motor alternators and transformer at a periodicity of 500 cycles per sec. and is smoothed for CW transmission by means of choke and condenser units; for ICW transmission the smoothing unit is disconnected, and the emission is consequently modulated at double the frequency of the high tension supply, viz; 1000 cycles per sec. which is the emitted note frequency of the ICW transmitter.

The signaling key and a power switch which may be adjusted to 1/16, ¼, and full power, are included in the main transformer primary circuit; the power switch is provided to facilitate compliance with the operating regulation calling for the use of minimum power for effective communication.

Emergency Transmitter. The emergency transmitter is a self-contained unit of the panel type and is designed to operate with a total power input of 100 watts at 12 volts from the battery of 120 ampere-hour cells referred to above.

Telephony Installation. This comprises a self-contained transmitting and receiving set arranged for operation on the waves 200 and 220 meters; the normal rating of the set is 500 watts. This set is used for communication with fishing trawlers.

Receiving Apparatus. The main receiver at the station is the direction finder receiver comprising; a goniometer, coupled tuned circuit, 6 stage radio-frequency aperiodic transformer coupled amplifier, detector and 2-stage low frequency amplifier. In addition, a 4-valve receiver is provided for use in the event of interruption to the direction finding receiver.

Special switching devices are adopted to protect the receivers during transmission and to ensure that the operator shall not take a bearing unless all other aerials on the site are isolated from earth.

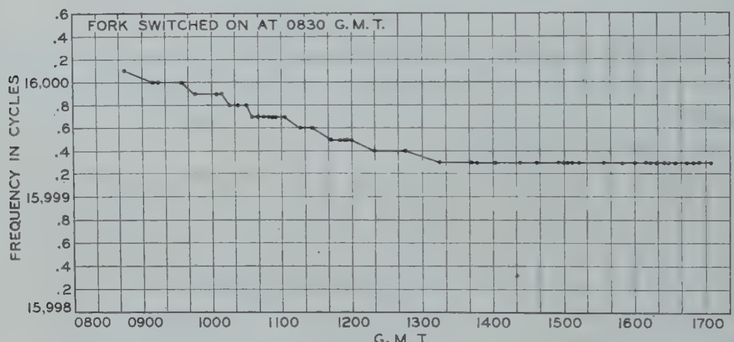

Fig. 3

Long Distance, Long Wave Telegraph Service

These services are carried out from the Rugby Radio Station, the erection of which was primarily undertaken to provide telegraphic communication with all parts of the British Empire and ships in any part of the world.

The high power telegraph transmitter was brought into operation January 1, 1926. Technical descriptions of the plant and special details in the design have been published in British technical journals.[1]

A constant frequency source of high-frequency energy is provided by a tuning fork oscillator operating on a fundamental frequency of 1777.7 cycles per sec., the 9th harmonic of which is utilized and the emitted frequency being 16 kc per sec. The tuning fork is of elinvar

[1] E. H. Shaughnessy, *Jour. I. E. E.*, **64**, 683, 1926; R. V. Hansford and H. Faulkner, *Jour. I. E. E.*, **65**, 297, 1927; A. S. Angwin and T. Walmsley, *Proc. I. C. E.*, **221**, 201, 1926.

which has a temperature coefficient of approximately 3 to 4 parts in 10^6 per deg. C.

An actual record of the frequency variations of this transmitter is shown in Fig. 3.

This oscillation is amplified and impressed on the grid of a high power amplifier consisting of 54 10-kw water-cooled valves. Five units are provided, each equipped with 18 valves and under normal conditions three units are used. High tension direct-current supply to this amplifier is provided by three 500-kw direct-current machines each capable of generating 6000–7000 volts. If desired, two or more machines can be connected in series to give voltages up to 18,000 volts. The total power input to the transmitter is of the order of 500 kw and the aerial power 350 kw corresponding to an aerial current of 750 amperes.

Twelve insulated 820-ft. lattice steel masts, stayed and pivoted at the base are used for the Rugby aerial systems. They are designed to withstand a uniform wind load of 60 lb. per sq. ft. and a horizontal antenna pull of 10 tons at the top. The telegraph aerial is of cage type supported by eight of the masts, arranged to form an elongated octagonal figure with sides of 1320 ft. In order to avoid overloading of the mast the steel rope supporting the aerial insulators passes down the center of the mast and is attached to a drum fitted with a slipping friction brake so adjusted that the rope is slackened when the load exceeds 10 tons. The copper-wire buried earth follows the plan of the aerial and extends 800 ft. on both sides of the vertical projection of the aerial on the ground.

In order to investigate the conditions of reception of the Rugby telegraph transmitter at long ranges, particularly in tropical locations, a series of measurements were made by Post Office engineers on a voyage between England and New Zealand via the Panama Canal, special attention being directed to a comparison between the relative efficiencies of a pure sinusoidal wave of constant frequency emitted from a valve generator such as the Rugby transmitter and arc or alternator transmitters.

Measurements were made of signal strength and noise throughout the voyage. The noise was measured by comparison with a signal and the "noise factor" plotted on Fig. 4 may be defined as three times that signal which is just inaudible when both signal and noise are impressed on the receiver. In practice it was possible to read signals which were greater than the "noise factor" so determined and thus, by taking the percentage of the day when the signal field exceeded the noise factor, a "commercial factor" was obtained for the station under

observation. In Fig. 4 are plotted field strength and noise factor for the outward run. The noise factor curve shows the enormous increase in noise in the tropical zones and readily explains why reliable com-

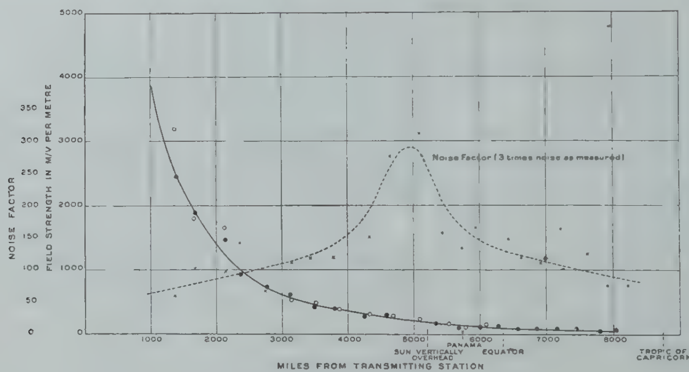

Fig. 4—Average daily field. Outward run.
○ L Y. (Daily averages of actual readings uncorrected for current)
● G. B. R. (Reduced to 500 amperes)
× Noise factor

munication cannot at all times be obtained in such regions. The commercial factors of Rugby and Bordeaux are shown in Fig. 5. Since that date the aerial current at Rugby has been increased from 500 to 750

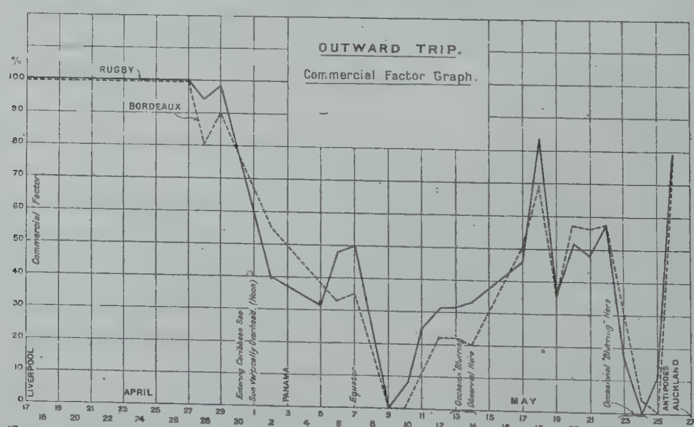

Fig. 5—Outward trip. Commercial factor graph.

amperes, which gives some slight improvement in the commercial factor.

The general results of the expedition showed that Rugby's field at equal distances from the transmitter is generally stronger than that

of any other station but that in some localities the strength of atmospheric disturbance is so appreciably above the signal strength as to render reception inaudible. To overcome this disabilty advantage has been taken of the fact that short waves are much less affected by atmospheric interference and long and short waves do not always fade simultaneously, and a short wave service is now operated in parallel with the long wave service for press broadcasts.

In the neighborhood of the antipodes of transmitting stations marked variations were observed in the fields of these stations at places a few hundred miles apart. In particular near the antipodes of Bordeaux the signals of that station increased to over four times the average in that area and were stronger than those of any other European station.

Point-to-Point Radio Telegraph Services

In addition the Post Office conducts radio services with the following Continental countries, viz., Italy, Czechoslovakia, Danzig, Esthonia, Hungary, Rumania, and Poland, also a broadcast financial news service is transmitted by Leafield (G.B.L.) to all Continental countries for news agencies. Wireless services can also be brought into use in the event of cable breakdowns to Germany, Norway, Holland, and Iceland.

The transmitters used are situated at Rugby and Leafield, approximately 90 and 70 miles distant from London, respectively. The receiving station is situated at St. Albans, 14 miles from London. Transmission and reception of the services is controlled by the Central Radio Office, London, the transmitters being oprated by remote landline control. The received signals are relayed to this office by St. Albans, no operating being done at the relay station at St. Albans.

Central Radio Office.

The Central Radio Office is located in the Central Telegraph Office, London, as this is the handing in and delivery point of the bulk of the traffic. The transmitter control sets are ordinary double-current duplex Wheatstone sets, and all transmission, irrespective of the speed required is invariably carried out by a Wheatstone transmitter. Two transmitters are fitted to each control circuit and in the event of a fault developing, a quick change-over can be made by means of a switch. Aerials on the roof of the building are connected to radio receivers in the office. These sets are tuned to the various transmitting stations in use and supply loud-speaker signals at the control

positions, thus supplying a check on transmission and land line apparatus.

Incoming signals from the distant stations are normally received on a Creed automatic perforator and printer, a Wheatstone recorder being provided in leak for check purposes or whenever atmospheric conditions render direct printing unreliable.

Transmitters. Four medium power long wave transmitters are employed for these point-to-point services three of which are at the Leafield Station and one at Rugby.

The final amplifying stage in the case of the Leafield transmitters consists of six 10-kw water-cooled valves in parallel, excited by a one-kw-dissipation air-cooled glass valve which in turn is excited from a standard type of Post Office tuning fork control unit.

At Leafield, power is derived from turboalternators installed in the station. The two main sets have a full load output of 250 kva at 3300 volts and two auxiliary turbines coupled to 60 kw, 220-volt d-c generators for auxiliary supplies.

A hexaphase thermionic rectifier unit supplies the high tension direct-current power to the transmitter and the input is 70–80 kw at 9000 volts.

Keying is carried out in an early high-frequency stage of the tuning fork unit by means of a Creed relay. Speeds of 200 words per minute are possible.

The aerials are supported by ten 300-ft. tubular steel masts. Some of the aerials are led directly into the building but the aerial at the far end of the site is terminated in a hut approximately 1100 yards from the building and is fed through a transmission line.

During the summer period when conditions are difficult on long waves, all services are supplemented by short wave.

The two short wave transmitters deliver approximately 8 kw to the aerials. The method used for controlling the frequency is by means of a crystal oscillator, the crystals being operated at a frequency of two or three megacycles per second, and followed by two or three doubling stages according to the wavelength in use. The output from the last doubling stages is inductively coupled to the first amplifying stage of 500 watts. The output from this stage is capacity coupled to the next amplifying stage of 3 kw. The output from the 3-kw stage is coupled to the grids of two 10-kw water-cooled valves by means of variable capacity coupling. The anode of the final stage is inductively coupled to the transmission line in use.

Provision is made for suppressed wave or modulated keying, the keying being carried out by means of a relay in the 500-watt stage.

Receiving Station.

The St. Albans Receiving Station occupies a site of roughly 1000 ft. square. The main building is situated in the center. The ground floor of the building is devoted to power plant and batteries while the receiving apparatus is housed on the floor above.

Around the building are grouped eight masts arranged in two sets each consisting of four masts occupying the corner of two concentric squares. The outer square is composed of four 200-ft. high steel lattice self-supporting towers and the inner square of four 120-ft. steel tubular masts. Eight open aerials and the Bellini-Tosi aerials are carried by the 200-ft. masts and four open aerials by the 120-ft. masts.

Power is obtained from the public supply mains in the form of 3 phase alternating current at 415 volts.

Ten long wave radio receivers are installed covering a wavelength range from 3000 to 20,000 meters. The sets are of commercial type built in units, each unit being carefully and separately screened. They consist of aerial tuning units, two stages of high-frequency filter, three stages of high-frequency tuned and neutrodyned amplification, one stage anode bend rectification, four stages of low-frequency filter (tuned grids) and three stages of low-frequency amplification. One power panel controls all low tension and high tension feeds and grid bias on all valves. Facilities for recording signals are provided on all sets, the signals being first amplified and then converted into double current for working telegraph relays. Each set has a Wheatstone receiver in leak, by means of which the recorded signals passing to line can be observed.

Four short wave receivers are provided. These sets are of the double detection type with band filters. Each amplifying stage comprises two valves arranged in push-pull and each stage is carefully screened. Suitable limiting and recording valves are provided and the receivers are capable of working up to speeds of 400 w.p.m.

Fourteen telephone loop circuits are provided between St. Albans Station and the Central Telegraph Office, London. The aural signals are passed forward on the loops and the recorded signals are superimposed across the loops. In addition, one loop is used for a telephone with a telegraph circuit superimposed to provide communication for purposes of traffic control between the Central Radio Office and St. Albans.

IV. Point-to-Point Radio Telephone Services

The telephony plant at Rugby has grown from one long wave transatlantic telephony transmitter installed in 1926 to one long wave

and six short wave transmitters in 1930. It is anticipated that by 1933 one long wave and at least six short wave transmitters will have been added to the present plant. A plan of the site showing the layout of the masts and buildings is shown in Fig. 6.

The existing long wave transmitter was installed in the main building 1925–1926 by the Standard Telephones and Cables Co., Ltd. under the direction of the Bell Telephone Laboratories and in coöperation with the British Post Office. It was with this transmitter alone that the transatlantic telephone service was opened in 1927.[2]

The first experimental short wave transmitter was installed by the Post Office in 1928 and was used as an auxiliary to the long wave circuit on the transatlantic service. This transmitter was replaced by a new transmitter in 1929 and is now used as a standby and for experimental development work.

The next two transmitters were installed in 1929 in a small temporary building used during the construction of the main station. These came into operation on the transatlantic telephone service in June and August of that year. One of these was installed by the Standard Telephones and Cables Company, Ltd., and the other by the Post Office.

In 1928 plans were prepared for a new building to house an additional long wave transmitter for the transatlantic service and nine short wave transmitters. The first section of this building capable of housing three transmitters was commenced immediately and before the end of 1929 a third short wave circuit installed in this building was added to the transatlantic service.

In the early months of this year the remaining two transmitters in this new section were brought into operation, the first for a ship and shore service and the second for the telephone service to Australia which was opened on April 30th.

This rapid rate of expansion and the decision made in coöperation with the American Telephone and Telegraph Company to provide a second long wave transatlantic circuit rendered it necessary to proceed with the erection of the remainder of the new building which has just been completed. Already contracts have been placed for two more short wave transmitters and for parts of the equipment for the new long wave transmitters. The former will be used for telephone services to the British Colonies or to South America. A block schematic of the new building as it will appear when completed is shown in Fig. 7.

[2] A. A. Oswald and E. M. Deloraine, *Electrician* 96, 572, 1926; A. G. Lee and R. V. Hansford, *Jour. I. P. O. E. E.*, 20, 52–55, 1927.

All the short wave transmitters consist essentially of
(1) power switchboard and high tension rectifier,
(2) line amplifying equipment,
(3) crystal oscillator and doubler units,
(4) intermediate amplifying stages,
(5) high power amplifier,
(6) control desk.

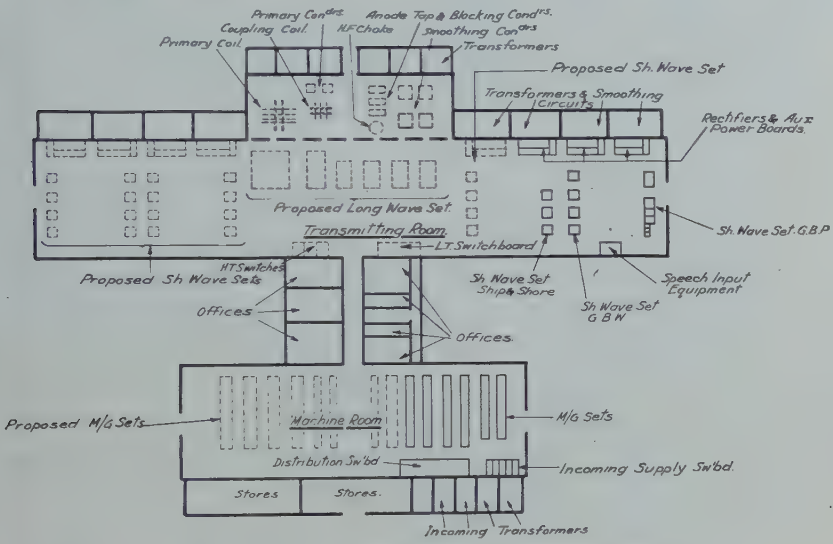

Fig. 7—Rugby radio station. New building.

The modulated power output on telephony from the final stage is 8 to 12 kw depending on the wavelength. If desired the penultimate stage can be switched on to the aerial transmission lines in lieu of the final stage when a power output of 3–5 kw is obtained. Balanced push-pull circuits are used throughout on the amplifying stages. The crystals are fitted in thermostatically controlled ovens the temperature being maintained constant to within ±0.1 deg. C.

Each transmitter is capable of operating on three or four wavelengths in a band from 15-50 meters, facilities being provided for rapid change from one wave to another. Fig. 8 shows the frequency variation of the latest transmitter.

Reception—General.

The problem of long distance radio reception is that of obtaining a commercial signal-to-noise ratio.

The factors involved in producing this result are variable in every

case and a somewhat detailed statement of the solution adopted at the British end of the transatlantic telephone circuit may be of interest.

Long Wave Transatlantic Telephone Circuit.

In order to occupy as narrow a band as possible and to keep the size of the transmitter as small as possible the single side-band suppressed carrier system, developed by the American Telephone and Telegraph Company, is used on this circuit. The signals as received on the antenna are not intelligible until the carrier frequency is supplied by a local oscillator and for good quality speech this added

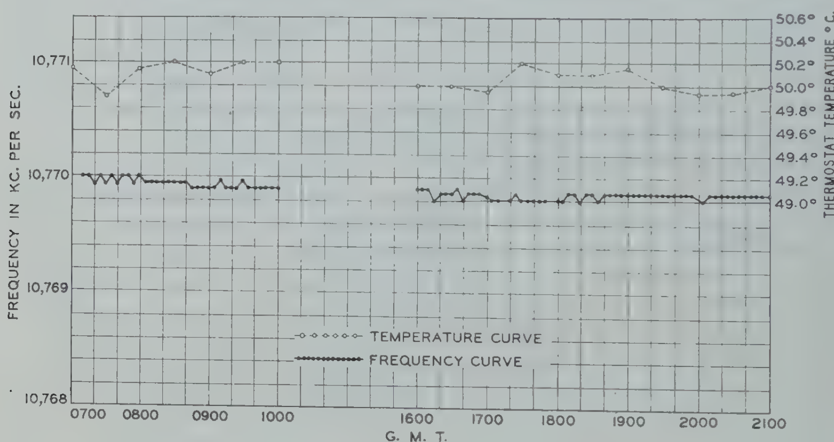

Fig. 8

frequency must be adjusted and maintained to within a few cycles. This means that all the oscillators on the channel must be extremely constant in frequency and it is for this reason that this method of transmission has not yet been utilized for the short wave channels.

For the transmission of good quality speech it is sufficient to transmit the band of frequencies 400 to 2750 cycles per sec., and if the carrier frequency is 58.5 kc per sec., as on the existing circuit, the radio receiver must receive the band 58.75 to 61.25 kc per sec. and, as far as possible, suppress all others. The Post Office receiver at Cupar is of the single detector type and a large proportion of the selectivity is obtained by means of a high-frequency band-pass filter before the first valve which is thus protected against interfering stations outside the above mentioned band. The frequency attenuation characteristic has slightly rounded corners (see Fig. 9) but this is compensated for by means of the two coupled-circuit band tuners which follow it. The

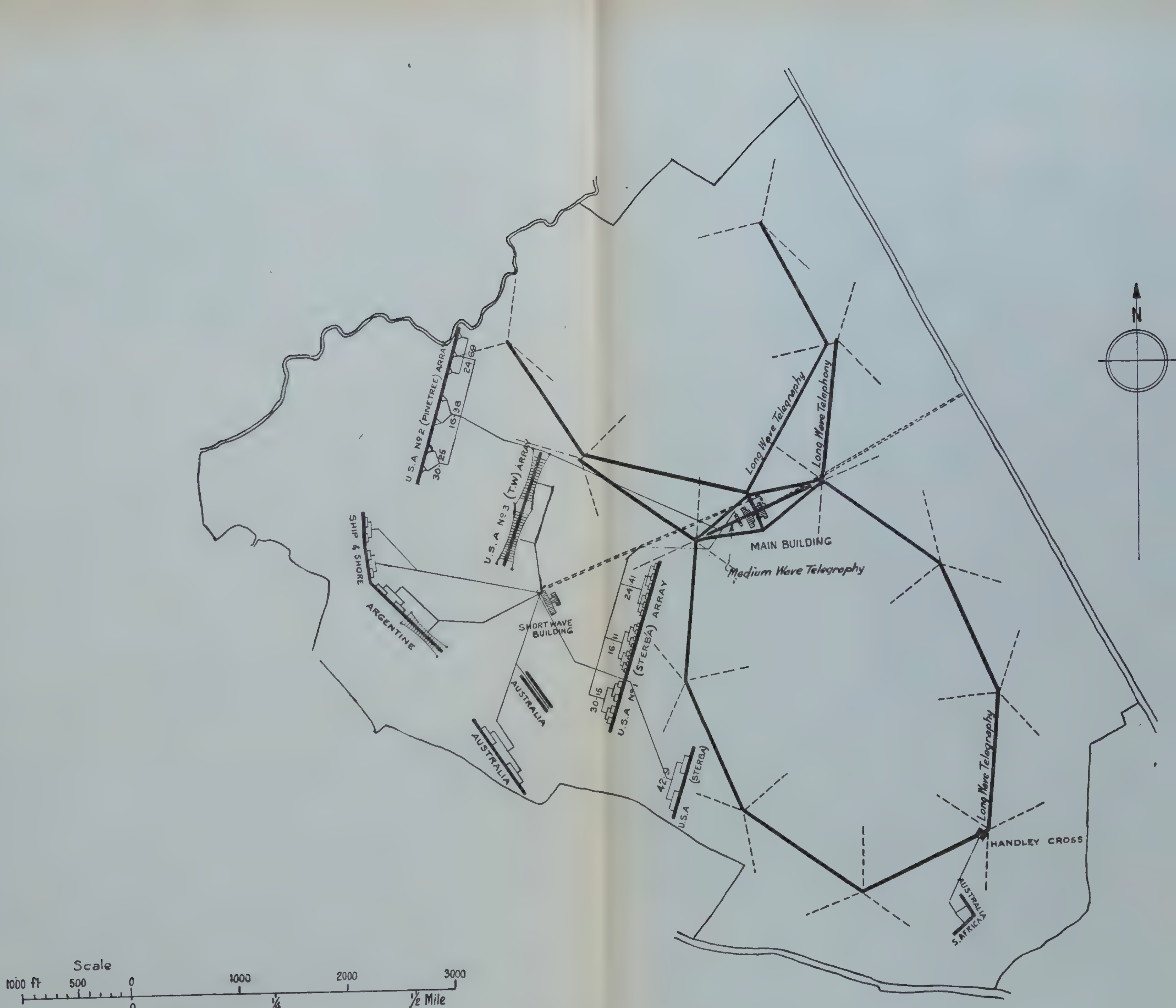

Fig. 6—Rugby radio station.

frequency attenuation characteristic of these has a dip in the middle of the band and high corners and the resulting over-all curve shown in Fig. 10 is substantially flat over the required band.

The band-tuner units amplify in themselves but additional high-frequency amplification is provided by a transformer coupled amplifier. The carrier frequency is applied just before the demodulator valve and the voice-frequency currents are passed through audio-frequency low- and high-pass filters and amplifiers into the line equipment.

A schematic diagram of the receiver is given in Fig. 11 and it will be seen that the high-frequency filter consists of two parts, a low-pass filter followed by a high-pass one which together give the effect of

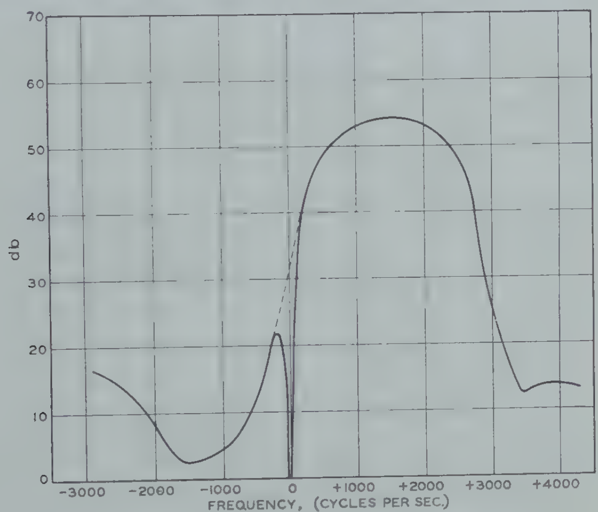

Fig. 9

a band-pass filter. This system was chosen because the values of the components for the normal types of band-pass filters having a band width of 3000 cycles per sec. at a mid-band frequency of 60,000 cycles per sec. were difficult to obtain. In order to set the carrier oscillator to the correct frequency a 1500-cycle-per-sec. tone is applied to the transmitter and the received signal is adjusted to this frequency by beating against a 1500-cycle-per-sec. tuning fork, which can be maintained in oscillation by means of a valve.

Having obtained the maximum discrimination against undesired signals and atmospherics by the frequency selectivity in the receiver (which only passes the band required for intelligible speech) the only method of improving the signal-to-noise ratio is by the use of directional selectivity. In other words, the ideal would be to receive sig-

nals arriving from the direction of the transmitting station in America and from no other direction.

The averaged values of the relative intensity of atmospherics received at Cupar is shown on the curve in Fig. 12. These results were

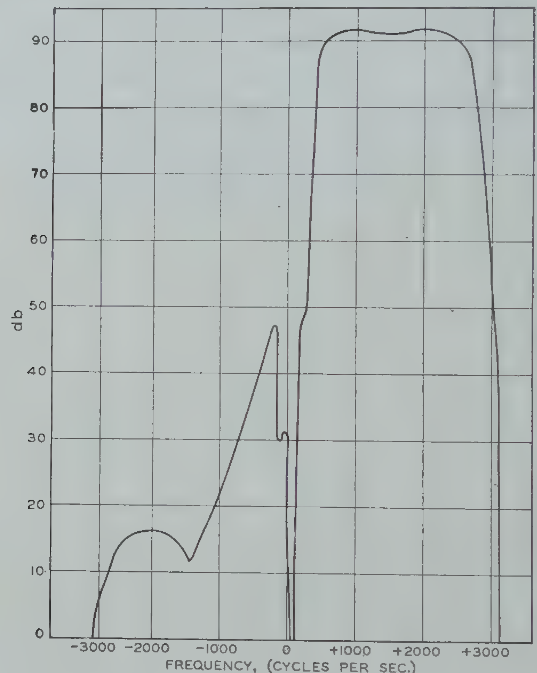

Fig. 10

obtained by using two direction finding sets utilizing cathode-ray oscillograph tubes. These sets were situated at Cupar and the Radio Research Board station at Slough, respectively, and therefore separated by a distance of approximately 400 miles, and were connected together

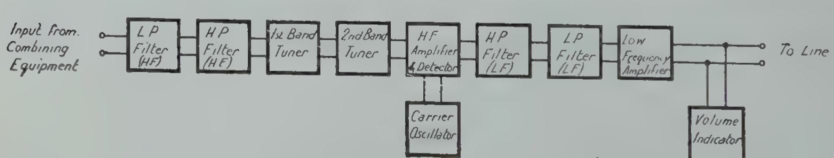

Fig. 11—Cupar radio station. Diagram of receiver.

by a telephone line. Simultaneous observations of the bearings of atmospherics arriving at the two places were taken. The intersections of the plots of these bearings gave the positions. The number and length of the deflections produced by the atmospherics gave an indication of the strength. It will be seen that, fortunately, the atmospherics

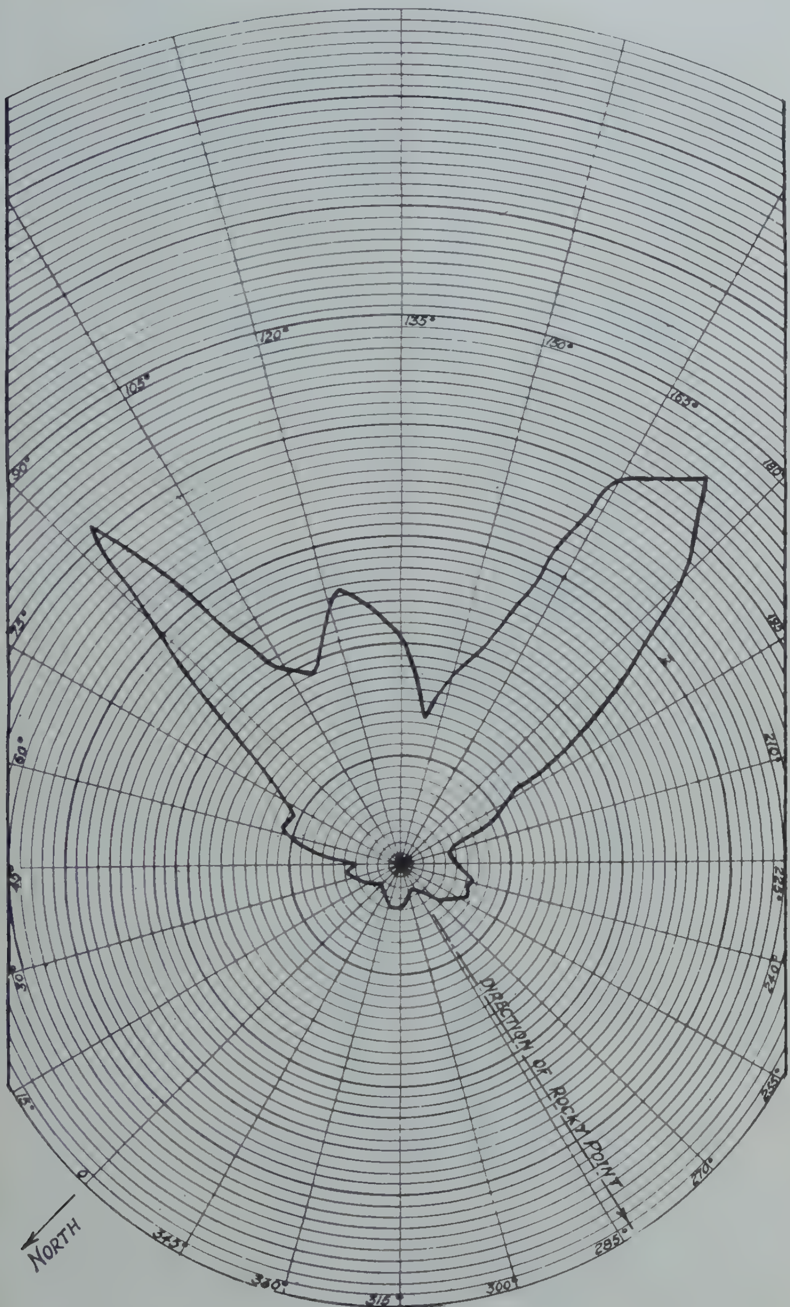

Fig. 12—Relative intensities of atmospherics at Cupar, 1929.

are weakest in the directiion of the required transmission and are very strong in the southeast quadrant, being largely produced by storms in Europe. It therefore follows that in order to produce the best circuit the antennas must be designed to be nonreceptive from the directions 80 deg. to 190 deg. from true north. The antenna system at Cupar now consists of six large loops with associated vertical antennas

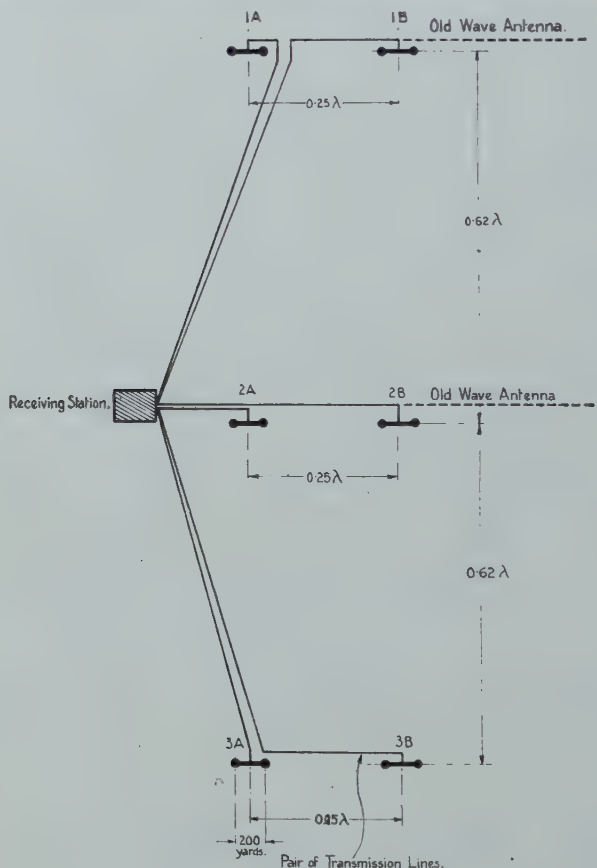

Fig. 13—Antenna system, Cupar.
λ = 5000 meters
Staggering distance = 1250 meters
Broadside distance = 3100 meters

arranged in three pairs as shown in Fig. 13. Each unit of a pair is spaced a quarter of a wavelength, i.e., 1250 meters, from its partner in the direction of the received signal and pairs are spaced 0.62 of a wavelength apart in a direction normal to that of the received signal.

The signals from the antenna units (each consisting of a loop and vertical) are led to the receiving station by six pairs of transmission

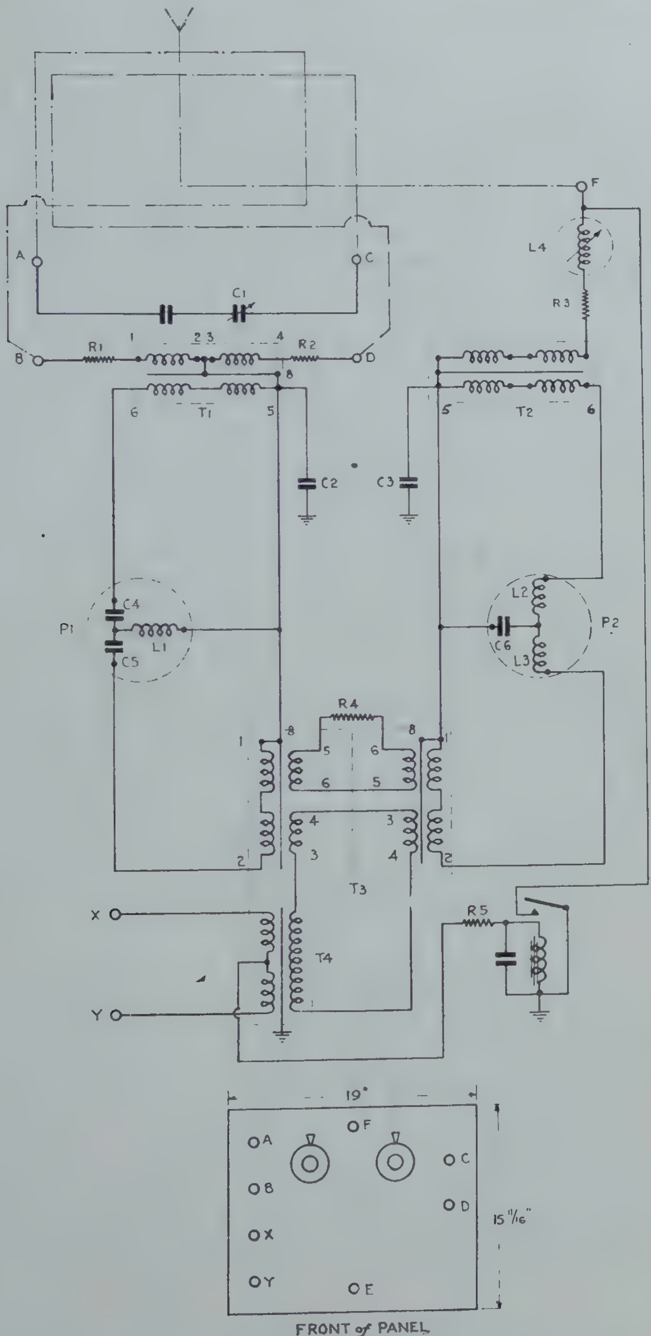

Fig. 14—Loop and vertical combining apparatus.

lines. These signals are combined to give the best directive characteristic.

Each loop antenna consists of four turns of silicon bronze wire supported by two 130-ft. steel lattice self-supporting towers spaced apart a distance of 200 yards. The top of the loop is 110 ft. above the ground and the bottom 20 ft. above the ground. The turns are spaced 4 ft. apart. The vertical antenna consists of a single horizontal portion stretching the full distance between the towers and therefore 130 ft. high, with the down lead at the center of the system. The outputs from the loop and vertical are combined by the apparatus shown in Fig. 14. The loop antenna is tuned by means of a variable condenser $C1$ joining the outer ends of the loop turns. The inner ends are taken to a high-frequency transformer $T1$ having a balanced winding with its center point earthed. The vertical antenna is tuned by the inductance $L4$ variable over a very small range by means of a copper plate which moves over the coil. $P1$ and $P2$ are phase shifters producing together a 90-deg. phase displacement in the currents from the loop and vertical antennas before they are combined in the double transformer $T3$. The resulting output is taken through a screened transformer to the transmission lines, X, Y, which go to the radio receiver at the radio station.

For utilizing the loops of the system only, relays are fitted at each antenna for cutting out the vertical portion and are operated by means of direct current from the receiving station. This condition of the antenna system is useful when atmospherics are coming from the direction around 190 deg. and also when electrified rain storms are occurring. The latter give rise to a continuous hissing type of disturbance and this is greatly minimized by cutting out the vertical antenna.

The following values may be of interest.

Inductance of loop antenna	$5350\mu h$
Capacity of loop antenna	$1060\mu\mu f$
Capacity of vertical antenna	$1285\mu\mu f$
Inductance of vertical antenna	$340\mu h$

It will be seen that at 60 kc per sec. the circuit constants of the loop and vertical are approximately equal. The damping of the two circuits is made similar by added resistance. Diagrams of the resonance curves for the loop and vertical antenna are given on Fig. 15. They are seen to follow one another fairly closely. The method of combination has the effect of making the impedance as measured at the output terminals of the combining apparatus approximately

600 ohms with very little phase angle at any frequency in the required band.

Directional Curves. For a true cardioidal diagram, i. e., for a zero reception point at 180 deg. from the front end to result from the combination of a loop and vertical aerial, it is necessary that the energy picked up (in the forward direction) by the two should be equal. If the energy of the vertical is smaller than that of the loop there results two directions of zero reception and these directions approach the front end as the vertical energy is decreased until with no vertical energy there remains the loop characteristic with zero reception at

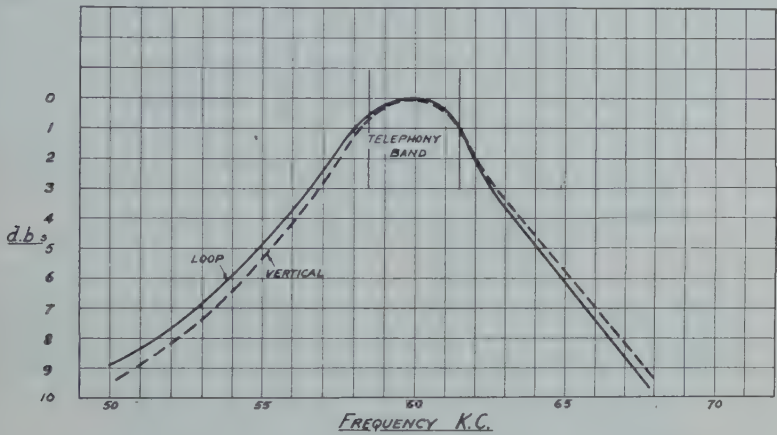

Fig. 15—Measured resonance curve for 3B loop and vertical.

90 deg. and 270 deg. to the front end. Such a system where the energy from the vertical is adjusted for particular conditions is termed a partial cardioid.

In addition to reducing the back end reception by the addition of verticals a zero at 180 deg. from the front end can be obtained by "staggering" two systems at a distance of a quarter of a wavelength apart and adding a phase displacement of 90 deg. (The term "stagger" will be applied to displacements in line with incoming signals and "broadside" to displacements at right angles to the line of the signal.) The directive characteristics for "staggering" of a quarter of a wavelength are given on Fig. 16, curve *A*. The effect of "staggering" the cardioids and partial cardioids is shown by curves *C* and *B* on the sheet. It will be seen that the reception from the back end is largely reduced by these means.

In order to make the curve of reception narrow. recourse is had to "broadsiding," i. e., using similar systems along the normal to the

line of signal reception. The characteristic curves for a triple arrangements with an equal spacing of 0.62 of a wavelength are given on Fig. 17. These curves show the effect of varying the ratio between the

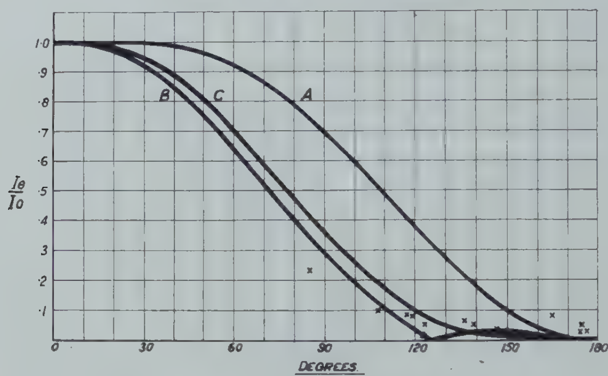

Fig. 16—Directive characteristics.
A = Staggering factor $\lambda/4$
B = Two partial cardioids at $\lambda/4$. Zero, 125 deg.
C = Two cardioids at $\lambda/4$
x = Measured values on pair of partial cardioids.

current of the middle and the outer antenna systems, the current from each of the outer antennas being equal. It will be observed for the ratio of 2 between middle and outer systems, the curve is smooth.

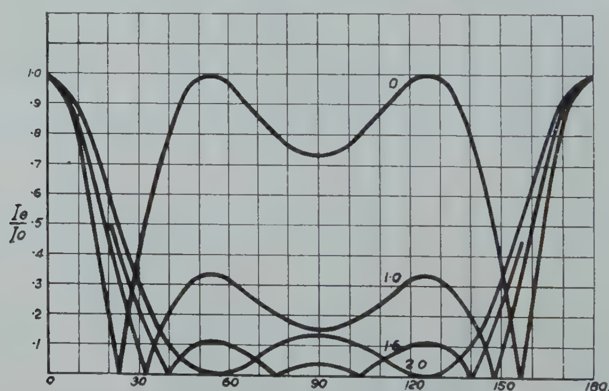

Fig. 17—Directive characteristics. Triple broadsiding factor for spacing 0.62λ for varying ratio of current.

Since the smooth curve has a wider angle of low reception it should be best for normal working.

The resultant curve obtained by correctly combining the systems, i.e., pairs of partial cardioids with zeros at 125 deg. staggered a quarter of a wavelength and triple "broadsiding" of pairs is shown on Fig. 18.

It will be seen that the reception has been limited to a large extent to a narrow sector in the forward direction. The combination of the current from the various antenna units is carried out at the station, where the apparatus for equalizing the currents and phase shifts from the respective antennas is installed.

Results obtained. The loops systems have been in use on the transatlantic telephone circuit since May, 1928, and satisfactory working has been obtained throughout, except at some of the sunset periods and for a few days when forward end storms have occurred. Before the above date, a wave antenna system was used. A direct comparison between a double broadside of wave antennas against a double broadside of pairs of loop and vertical combinations showed an average

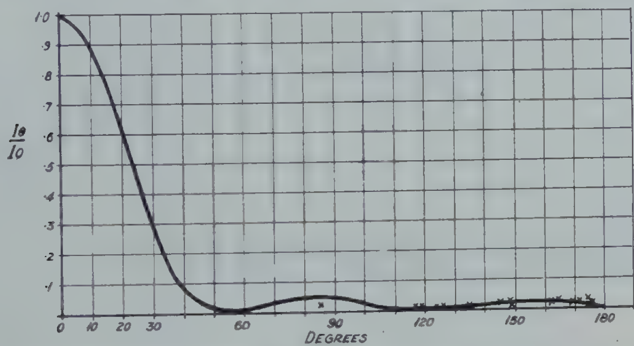

Fig. 18—Directive characteristics. Triple broadside of pairs of partial cardioids. x-Measured values.

improvement in favour of the loops of 2 db. The energy pick-up of the loop system over the old wave antennas shows an improvement of 4 db.

It will be seen that measured values have been inserted on some of the calculated directive characteristics. These measurements were taken on known telegraph stations whose frequencies were close to the telephony band. They necessitated simultaneous readings of absolute field strength and also the gain required on the calibrated main receiver to bring the signal up to the standard output level when using the antenna which was being tested.

It is customary to compare the signal-to-noise ratios of the antenna arrays against that of a single loop aerial and these improvement figures for 1929 are given below.

Average improvement of triple broadside of 3 pairs of partial cardioids over one large loop antenna 20.2 db

Average improvement of triple broadside of 3 pairs of cardioids over one pair of cardioids 5.8 db

Average improvement of double broadside of 2 pairs of cardioids over one pair of cardioids 3.9 db
Average improvement of triple over double broadside 1.8 db

It is proposed in the near future to add two more loop systems, that is, converting the antenna system into a quadruple array. It is hoped by this means to narrow to a still greater degree the directive curve on reception from the front end although not much improvement is expected from the back end directions as the existing balances are very good.

A similar quadruple system is now under construction at Cupar for the second long wave channel. This system is being designed for a mid-band frequency of 68 kc per sec. and is situated to the west of the existing system.

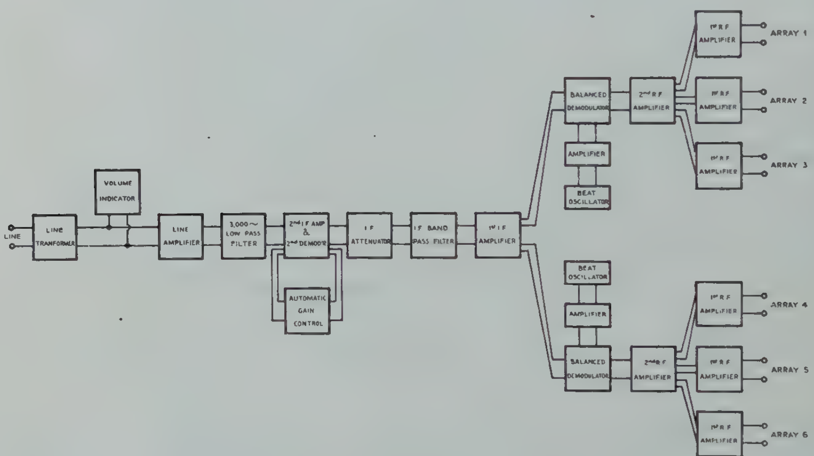

Fig. 19—Baldock short wave receiver.

Short Wave Channels.

Short Wave Channels. The short wave reception is being concentrated at Baldock, Hertfordshire, 40 miles from London and the arrays are situated around a central receiving building, the outputs from the various antennas being led into the building by special transmission lines.

The site of this station is some 900 acres in extent, in order to accommodate the multiplicity of short wave arrays which will be required. The ultimate capacity of the station will depend largely on the number of aerial arrays which can be accommodated but it is anticipated that this will be at least 16 short wave receivers and one long wave receiver. The long wave aerial system will be similar to that already provided at Cupar.

Besides the troubles experienced on long wave circuits, when the wavelength is reduced to the so-called short wavelengths, i.e., below 50 meters, fading of various types occurs. The receivers are therefore designed to have a large gain and are fitted with automatic gain control devices which keep the audio frequency output sensibly constant although the signal input may be varying as much as 50 db.

A schematic diagram of the Post Office receiver is given in Fig. 19 from which it will be seen that there are two stages of push-pull high-frequency amplification; the first stage being in triplicate for connection to three receiving arrays working on different frequencies The intermediate frequency amplification is performed by five

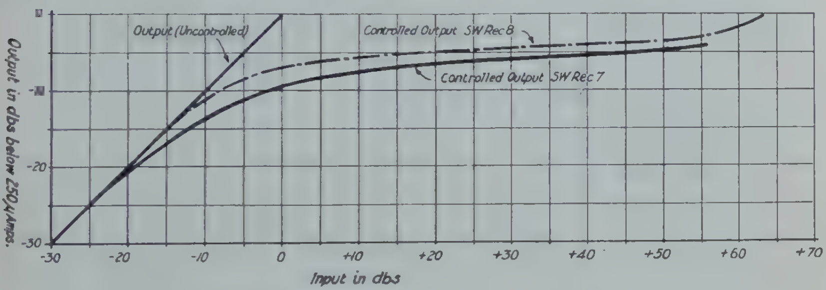

Fig. 20—Auto gain control for short wave telephony receivers.

stages of screened-grid valves and the selectivity obtained by the intermediate frequency band-pass filter. The automatic gain control is obtained by means of a separate detector valve, connected in parallel with the normal second detector. This valve has a high resistance in its anode circuit. The voltage drop across this resistance varies with the strength of the incoming carrier and is applied as a negative grid bias to the first valve of the main intermediate amplifier. Curves showing the control obtained are shown on Fig. 20. The selectivity of the high-frequency and the intermediate frequency stages is shown on Fig. 21 and Fig. 22 respectively. A photograph of the receiver is shown in Fig. 23.

It should be pointed out that one of the duties of the high-frequency stages is to supply sufficient selectivity to differentiate between the two frequencies which are separated from the beat-oscillator frequency by an amount equal to the intermediate frequency. In the Post Office receiver, this intermediate frequency is around 300 kc per sec. so these bands are separated by 600 kc per sec. and therefore the measured band width of the high-frequency circuits must be much less than 600 kc per sec. The band width is usually measured at

6 db down from the maximum value on the frequency transmission characteristic and it will be seen that on the 30 meter wavelength the band width is only 52 kc per sec. At 600 kc per sec. from the center of the band the attenuation is over 60 db. These stages give a gain of approximately 25 db on 30 meters and about 15 db on 15 meters.

The intermediate frequency filter has a loss of about 11 db in the pass band and therefore additional gain is supplied in the intermediate

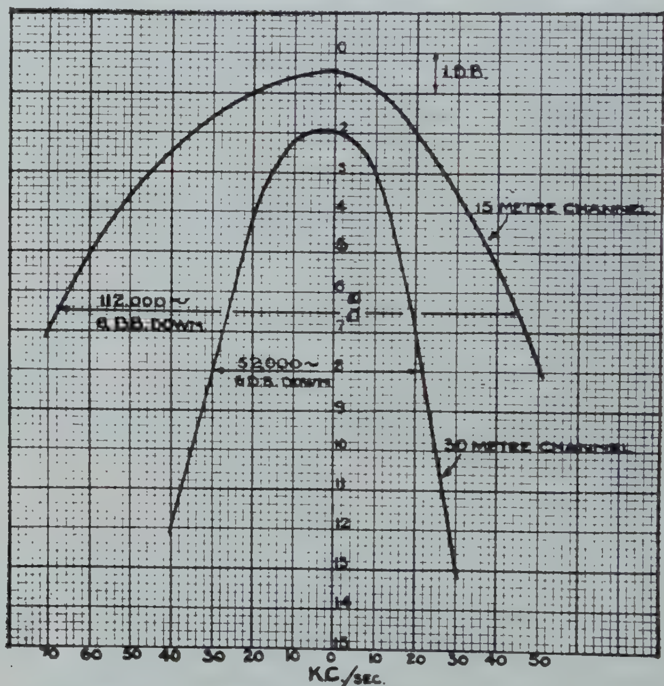

Fig. 21—Band curve of 15- and 30-meter high-frequency stages, on Baldock high-frequency receiver No. 6.

frequency amplifier to counteract this, and the over-all gain of this amplifier and filter is around 85 db; the band width being 9 kc per sec.

The measurement of over-all gains of the order of 100 db and above is always difficult and is more so when the input frequency is 15 megacycles per sec. Therefore, in order to check the gains it is usual to connect a vertical antenna a half wavelength long to the receiver and to generate a field from an oscillator situated at some distance from the receiver. The field strength at the same distance from the oscillator as the receiver is measured by means of a short wave field strength measuring set and a comparison between different receivers can thus be made.

When using a vertical antenna a half wavelength long, a received signal of 0.4 μv per meter on 35 meters is capable of working the second detector up to the level at which the automatic gain control starts to operate.

It is the experience of the Post Office that for short wave reception very much greater amplification can be used than in the case with

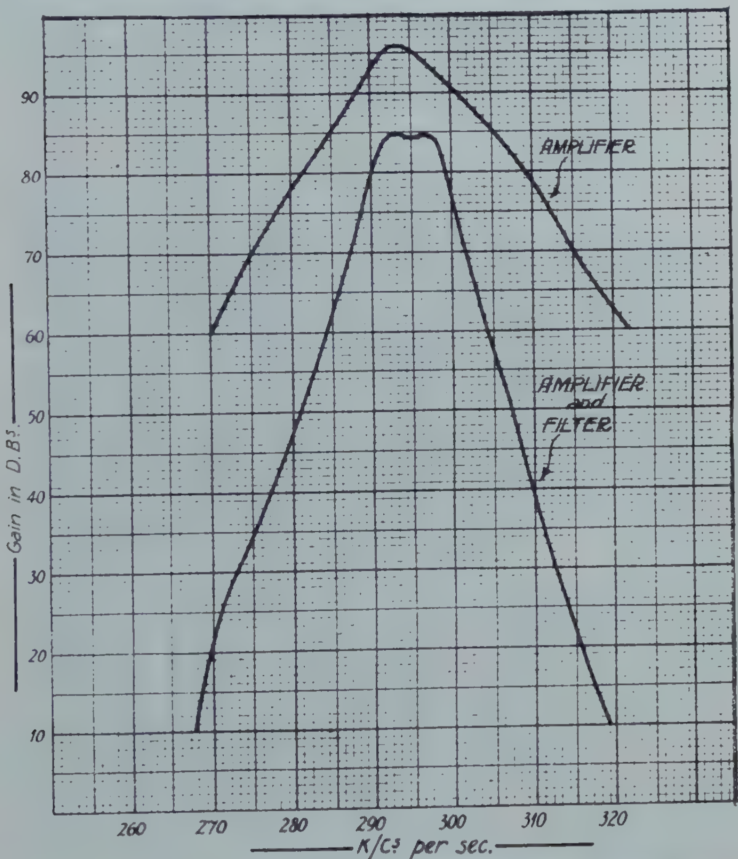

Fig. 22—Over-all curves of intermediate frequency amplifier and intermediate frequency filter for short wave telephony receivers.

long waves owing to the usual much lower noise level, and the full amplification provided on these receivers can at times be very usefully employed.

Both for radiotelegraphy and radio telephony purposes the British Post Office has built a large number of short wave directive aerials of various types. The Sterba and Bruce types, well known to American engineers, are in use for transmission and reception purposes respec-

tively whilst the Dutch (Koomans) type, both in its vertical and horizontal form is employed both for transmission and reception purposes. At Rugby and Baldock a modification of the Bruce aerial has been introduced with improved results over the original type. The single

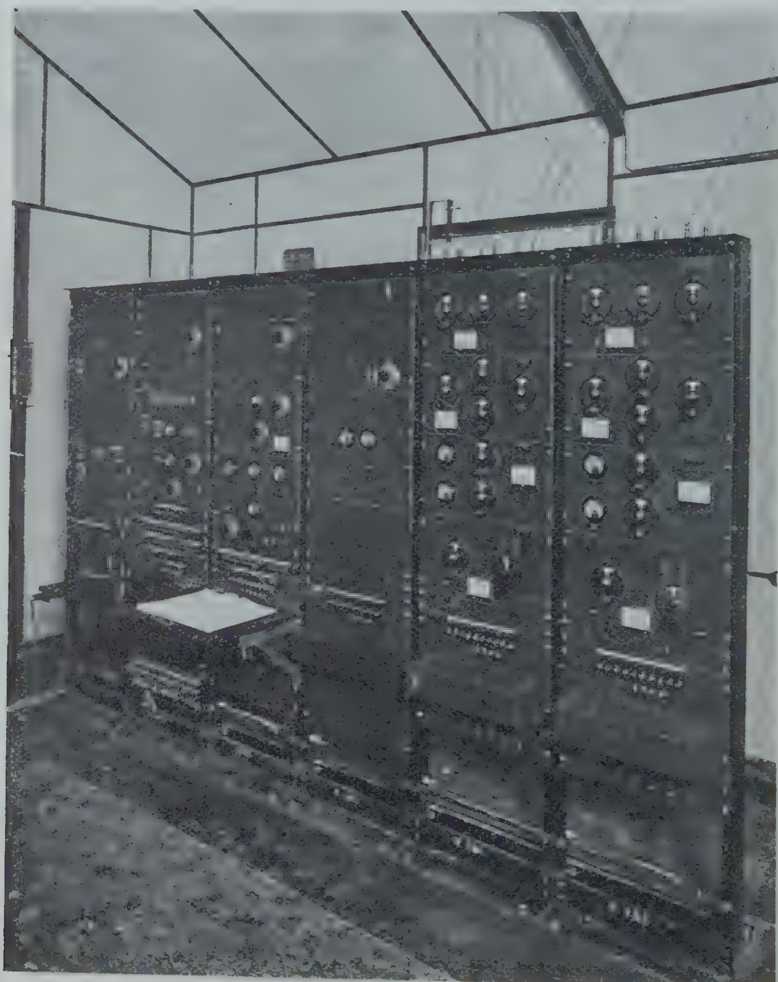

Fig. 23—Baldock receiver. Front view with operator's desk.

square pattern is retained but a second square inverted pattern has been added as shown in Fig. 24. The two halves thus constitute a series of vertical half-wave aerials separated one quarter of a wave apart. The reflector curtain consists of half-wave wires, insulated from each other and from the earth. Both the exciter and reflector

curtains are built of copper wire suspended from steel wire ropes. Experiments have also been carried out using large curtains of vertical and horizontal radiators suspended from the 820-ft. masts at Rugby.

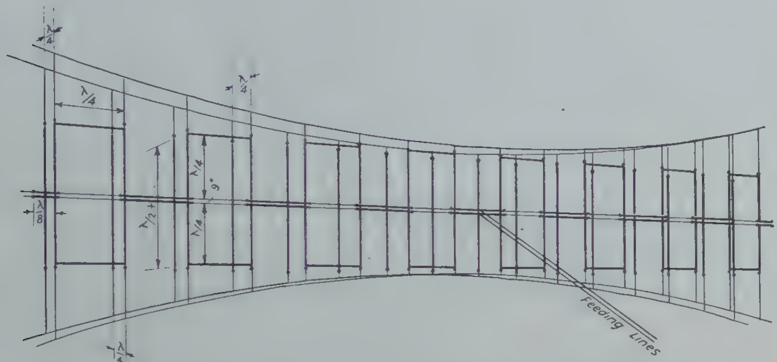

Fig. 24—Double key vertical array with reflector.

The experience of the British Post Office is that horizontal arrays having the same number of elements as vertical arrays and suspended from structures of the same height generally give a greater gain than the vertical type. From the various types of aerial systems now in

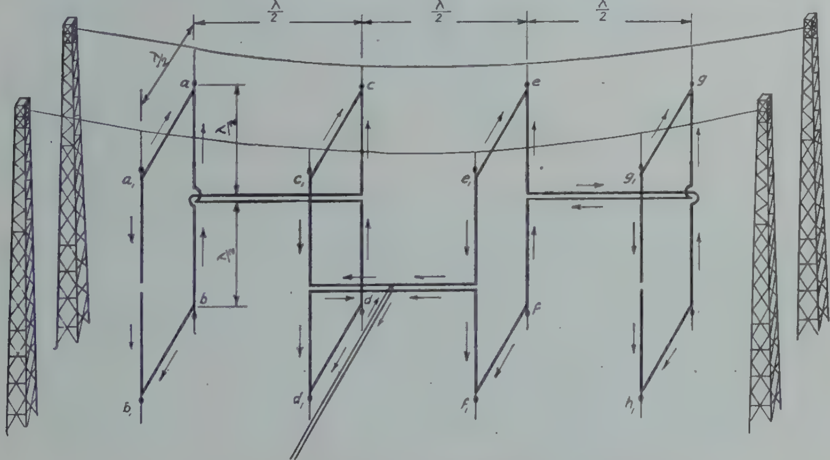

Fig. 25—"T. W." short wave aerial (single vertical unit).

use on different services, both for transmission and reception, experience is being obtained and data coördinated as to the most effective types for the diversity of frequencies, distances, and conditions for which directive propagation is adopted, but finality has

not yet been reached. The most recent development utilizes the fact that appreciable gain can be obtained by building arrays in two curtains one behind the other. An example of an array of this type designed by T. Walmsley, which has been used successfully on the transatlantic telephony service, is shown in Fig. 25. In effect, two curtains consisting of horizontal radiators spaced half a wavelength apart are erected one behind the other, the currents in the front curtain being 180 deg. different in phase from the currents in the

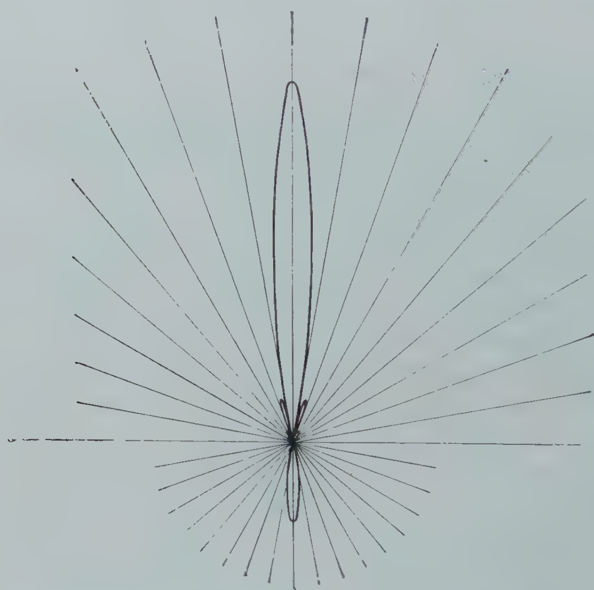

Fig. 26—Measured polar diagram in horizontal plane of "T. W." vertical 3-unit array. Span between end radiators 5½ wavelengths.

back curtain. Good reflection action is produced if a reflector curtain consisting of insulated half-wave elements is fixed about a quarter of a wavelength behind the back of the excited curtain. For example, in Fig. 26 in which the measured horizontal diagram of the vertical type of the array is given, the front-to back ratio of field strength is about 4.5 to 1 or 13 db. The array consists of 48 vertical directly energized radiators and 48 half-wave reflectors.

V. Radiotelephony to Ships

The development of a radiotelephony service to ships has followed the same general lines as that of short wave point-to-point radiotelephony with such modifications as have been necessary to allow

for the variability in the length of the path and divergence in the angles between the position of the ship and the land station.

The Rugby and Baldock stations are being employed for transmission and reception and the control is centered on the London trunk exchange.

Tests between Rugby and the "R.M.S. Olympic" commenced January 2, 1930. These tests gave such promising results that a commercial service was started early in February. The service is rapidly growing. There are now four ships fitted with radiotelephony equipment and it is probable that the future will see this number greatly augmented.

The transmitter used at Rugby on the marine service was built by the Standard Telephone and Cables, Ltd., and is very similar to those used on the London-New York circuit. The final power amplifier, however, only employs two water-cooled valves and the unmodulated carrier power in the antenna is 3–4½ kw.

It has been found necessary to utilize four different frequencies in order to span the Atlantic. At the Rugby Station the four frequencies used are

(a) 4975 kc per sec. (60.3 meters.)
(b) 8375 kc per sec. (35.8 meters.)
(c) 12780 kc per sec. (23.47 meters.)
(d) 17080 kc per sec. (17.56 meters.)

Of these (a) is used only to communicate with ships which are within one day's run of Southampton: (b) is used by day during the second and part of the third day out, and for night transmissions: (c) is used by day when the ship is in Mid-Atlantic and during evening periods; while (d) is used for day transmission only as the ship nears New York.

Horizontal transmitting aerials are used on all frequencies and have been found to give distinctly superior results to those obtained with vertical aerials. On 17,080 kc per sec. an array of 32 half-wave dipoles is used, giving a fairly concentrated beam along a center line 15 deg. south of the Rugby-New York great circle. On 12,780 kc per sec. another horizontal array of 24 dipoles gives rather a wider beam directed along a line 25 deg. south of the London-New York great circle. Simple arrays are used on 8373 kc per sec. and 4975 kc per sec. owing to the wide angles which have to be covered when the ship is near England.

The chief difficulty in this communication was expected to be in establishing reliable communication between Rugby and ships close in to Southampton. The difficulty however seems to have been

almost entirely overcome by the use of the 4975 kc-per-sec. frequency in conjunction with a simple horizontal array of four doublets, giving high angle radiation, and directed 20 deg. west of Southampton; and ordinarily, a ship can be worked right up the English Channel into Southampton docks.

The receiver at Baldock is similar to the transatlantic telephone receivers. Arrays having directional effects similar to those at Rugby are used.

The operation of the service presents several difficulties due to (a) the number of different frequencies employed, (b) the increasing divergence between ship and Greenwich mean time as the ship steams

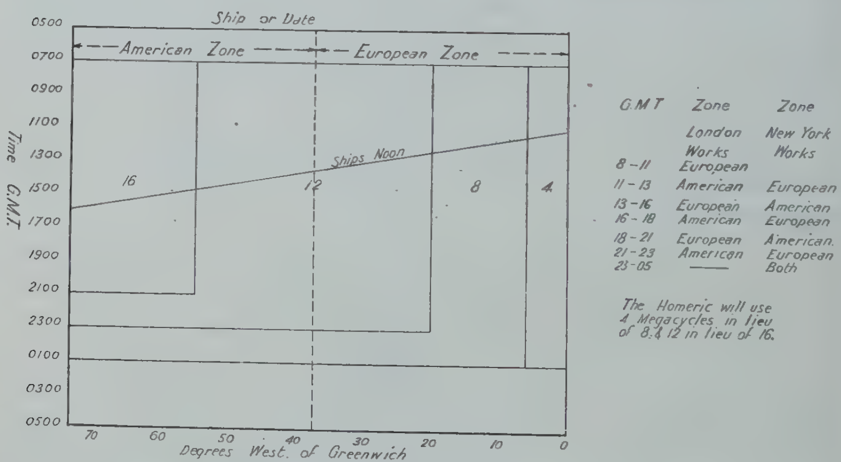

Fig. 27—Atlantic marine telephony frequency chart for May, June, July, and August.

west and (c) the fact that each ship has to work both to America and to England. Naturally these difficulties increase as the number of ships fitted with radiotelephony equipment increase.

The following method of operation as arranged between the American Telephone and Telegraph Company and the British Post Office is at present in use and is giving satisfactory results for the number of ships at present in commission. Each ship is provided with two sets of frequencies in each band, one set for working to New York and one for working to London. For convenience, the Atlantic is divided into "European" and "American" zones, the dividing line being the meridian 37 deg. 30 min. west of Greenwich. Each day is also divided into periods, usually each of three hours duration, and operating schedules are so arranged that, when London is working with

ships in the American zone, New York works ships in the European zone, and vice versa.

Each day, the approximate position of the ship and the expected days run are plotted on a special chart, both at the land terminal and on the ship. A typical chart is shown on Fig. 27. Reference to this chart then shows to the operators at either end (a) the time during which the ship should communicate with London or with New York and (b) the best wavelength to use on either service. (In cases where, during any period, the ship leaves one zone and enters another, the zone in which it will lie at the end of the period counts as the appropriate zone.) The ship, at the commencement of each period, tunes in its receiver and transmitter to the appropriate wavelength, and listens for the land station. The land station in the meantime, calls up any ship for which it has outgoing traffic and disposes of this immediately, if possible. It then calls up any other ship which is in the zone listening on the same wavelength, and, from it, receives any incoming calls. Then, if reference to the chart shows that other ships are in the same zone but should be worked on another frequency the land station changes over to that frequency, calls up the ships and receives any traffic which may be waiting.

The technical operators turn over the circuit to traffic without a formal line-up if it is evident that the circuit is commercial, and noise measurements, etc., are made during actual traffic. A period of five minutes only is allowed for establishing contact and generally this has been found to be quite sufficient.

In general the operation is simplified by the fact that the ship and shore stations before losing contact during any period, usually make arrangements with regard to frequency and time of work during the next period.

The British Post Office Voice-Operated Device for Radiotelephony Service.

The introduction of a voice-operated device for linking the public telephone service to the "four-wire" radio link was in the first instance provided to meet the special conditions of the transatlantic long wave telephone service but it is now used for both long and short wave circuits.

Though the method adopted in the linking of the two systems by radio may be likened to a four-wire circuit in so far that the terminal points are jointed by means of similar GO and RETURN routes the main differences between radio and ordinary four-wire circuits are inherent in the necessity of providing in one step, at the transmitters,

sufficient amplification of the speech currents to establish a certain minimum speech-to-noise ratio at the receiving end which must be exceeded if intelligibility is to be obtained.

In the development of the long wave radio link between England and America the restriction of available wavelengths rendered it necessary to utilize the same frequency band in the both directions. The problem was thus more difficult on account of the severe reaction that occurred between the radio transmitter and the local receiver.

At the start of the service the receiving station in England was located approximately 70 miles from the transmitting station at Rugby. The magnitude of the cross-fire from the local transmitter may be gained from the following typical field-strength measurements taken at the time.

Field strength of the U.S.A. transmitter—3.7 μv per m.

Field strength of the local transmitter—18,900 μv per m.

The difference in field strength is approximately 75 db.

Although some reduction of this difference was afforded by the wave antenna employed for reception, the discrimination was insufficient. A test showed that approximately 84-db loss was required to be introduced in the local loop to avoid a "singing" condition when an additional 30-db gain was introduced in the GO line to accommodate weak talkers from the land wire system.

It was found impracticable to provide in the receiving equipment or in the normal hybrid coil balancing arrangement located at the junction of the four-wire and two-wire portions of the circuit a balance by static means sufficient to offset this gain in the local loop and special voice-operated antisinging devices were therefore developed by the British Post Office and by the American Telephone and Telegraph Company for use on both ends of the circuit.

These voice-operated devices are similar in their general performance but their action may be said to differ in that the device developed by the Post Office operates wholly electrically by the use of thermionic relays, while the system developed by the American Telephone and Telegraph Company is one operated by electromechanical relays.

In the British system the desired loss is obtained by the insertion of special push-pull repeaters in the circuit which are rendered inoperative by the application of unidirectional direct-current voltages applied to their grids. These repeaters may have either zero or about 100-db loss corresponding to their operative and inoperative conditions, respectively.

To nullify the singing condition the method used consists in intro-

ducing the required loss by one of these repeaters in the GO line. Speech to be transmitted on this line by voice operation removes this loss and simultaneously transfers it to a similar repeater situated in the RETURN line. That is, when one path is operative the other is inoperative and vice versa. The net loss is also maintained during the transitory period.

Voice-controlled repeaters of this type have been found to be entirely satisfactory. Besides the rapidity of operation possible by the use of the thermionic valve is the advantage that they can also serve as amplifiers in the circuit.

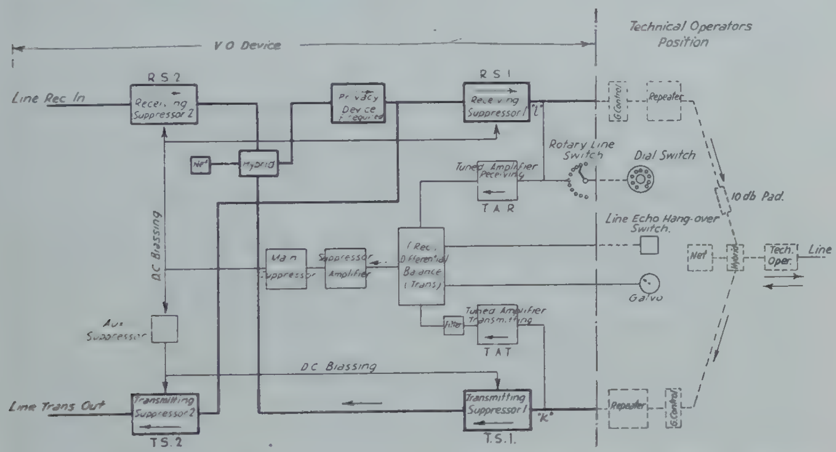

Fig. 28—Schematic diagram of voice-operated device. For privacy switching and suppression of singing and echos.

The method of suppressing the repeaters on the RETURN side is similar to that developed by the Post Office for the purpose of suppressing echoes on wire line repeatered circuits; speech on the GO line being applied to a rectifier system, the unidirectional voltage thereby produced being applied to the grids of the repeaters.

The repeaters in the GO side are operated in the reverse sense, a grid-biasing voltage being removed when the local talker speaks. This is effected by causing a proportion of the unidirectional voltage developed by the same rectified system to render negative the grid of a separate valve. In the normal condition the plate current of this valve applies a negative voltage to the grids of the repeaters and when the unidirectional voltage is applied to it the plate current disappears and the repeaters automatically become primed at their proper value for speech transmission. The voltages remain held during the passage of connected syllables by a resistance condenser combination incorporated in the rectifier system. Fig. 28 shows a block schematic

circuit diagram of the voice-operated apparatus together with associated amplifiers and line.

The loss introducing repeaters or suppressors are shown as $TS1$ and $TS2$ and $RS1$ and $RS2$ in the transmitting channels respectively while the controlling apparatus producing the biasing voltages are shown tapped off the points k and l. These T's are of high impedance relative to the line and introduce little or no loss to the passage of the speech currents.

The suppressors $RS1$ and 2 are, in the normal condition, free to receive the incoming speech from the radio receiving station while the transmission path of the GO line is blocked by the suppressors $TS1$ and $TS2$.

When the local subscriber talks the receiving path through $RS2$ and $RS1$ is suppressed and the suppressors $TS1$ and $TS2$ are made operative for the transmission of speech. Upon the cessation of the local talker's speech the system reverts instantly to the normal condition.

The received speech currents passing out of $RS1$ to the extension lines is impressed through the amplifier TAR to another rectifier system in the differential balance unit. The function of this rectifier system is to prevent the unbalance currents which pass across the hybrid coil at the four-wire termination, and the line echoes of the speech or atmospherics passing out to the land wire extension, from causing a false operation of the voice-operated system. It ensures that the device will only be actuated from voice currents emanating from the local talker. Delayed restoration of the differential balance unit to normal, after the echoes have been dissipated, is governed by the line echo hangover switch which is adjustable for long, medium, or short extensions.

When atmospherics are heavy, or, when other interfering noise is picked up at the receiving station the differential balance will be actuated on the receiving side by these noise currents. In these circumstances the gain of the amplifier TAR actuating the differential balance on the receive side is reduced by means of the switch provided on a control panel.

The British Post Office has at the present time six of these devices in daily operation at the London terminal. They are employed on both the long and short wave circuits. Although local singing does not exist on the short wave circuits the devices are necessary owing to the extreme variability of the conditions on the transmitting path.

The devices have enabled telephone conversations to be made without difficulty from subscribers in most of the principal cities in Europe to America and elsewhere via the radio terminal in England.

For the majority of the calls between these long distance land wire connections a better connection is afforded by virtue of these devices than would be obtained were the normal land circuits linked directly. For example, the net circuit attenuation to London of a land line subscriber on the Continent or in a remote part of England might be of the order of 25 db. Linked to a similar long distance in another country the over-all attenuation experienced by each of these listeners might possibly reach the lower limit of practical audibility—say 50 db.

Since singing is prevented in the radio link it becomes possible under good radio and line conditions to connect these subscribers by means of a circuit possessing a negative transmission equivalent in either direction of 30 db. This means that the audibility between these talkers is improved to this extent.

Broadcasting.

Under the provisions of the Wireless Telegraphy Acts, the Postmaster General is the licensing authority for all transmitting and receiving stations in Great Britain and Northern Ireland. He thus licenses, amongst others, the British Broadcasting Corporation, users of wireless (broadcast) radio receivers, and amateur transmitters.

The British Broadcasting Corporation is a body separate from the Post Office, governed by a Board appointed by the Government, and derives its revenue from broadcast license fees collected by the Post Office. Coöperative working between the two is necessary, in view of their joint interests. The Post Office is mainly concerned with the following matters relevant to the British Broadcasting Corporation.

(1) The provision of telephone lines between studios and transmitters.
(2) The provision of lines for special and outside broadcasts.
(3) Questions relevant to the transmitting licenses e.g., regional stations, multiple station working, transmitter powers.
(4) Questions relevant to the receiving licences e.g., electrical and oscillation interference.

Of these, (4) involves dealing with the public, and some slight explanation of the Post Office activities will not be out of place.

Licenses for broadcast reception are obtainable on demand at any Post Office. The license forms show the various conditions covering the issue of the license, and include clauses in connection with the Postmaster General's right to inspect stations, the moderate use of reaction, aerial length, the privacy of other than British Broadcasting Corporation transmissions, and the correct installation of mains-operated sets. It will be appreciated that as the licensing authority is the

Postmaster General, the Corporation has no right to inspect receiving stations. Cases of interference, therefore, although directed to the British Broadcasting Corporation in most cases, can only be investigated by the Post Office.

The general procedure as regards interference thus entails the submission of complaints to the Post Office by the British Broadcasting Corporation, their investigation, and the ultimate report of the results of the investigation.

Particular cases—for instance tramcar and trolley-bus interference, battery charging plant interference, etc.,—are made the subject of special investigations.

As regards electrical interference, it should perhaps be pointed out that the Postmaster General has no statutory powers to enforce owners to adopt remedial measures. Nevertheless, it is found that owners of a faulty plant are usually willing to adopt the suggestions of the investigation officers.

At the present time, complaints of interference (electrical and oscillation), are received at the rate of about 5000 per annum total. Of these, approximately two-thirds are due to electrical installations. Interference from tramway systems are estimated as being 20 per cent of the total. Particular investigation of tramway interference has resulted in the evolution of a cure, but no great progress has been made to date as regards its adoption by tramway and trolley bus undertakings. Of the remaining cases, about 90 per cent are successfully terminated. By the distribution of relevant pamphlets, improvement in set design and advice given to listeners generally, trouble from oscillation appears to have been checked. It is certainly not increasing at the same rate as is the number of licensed listeners.

Amateur Transmitters.

There are about 1000 licensed amateur transmitters at present. These are limited to the use of one or more of the amateur bands (which have been suitably restricted in order to cover possible errors in frequency measurement). Particular conditions attached to the issuing of an experimental transmitting license are in respect of the power and method of frequency measurement. The maximum power normally authorized is 10 watts. Three hundred amateurs are licensed for the use of greater power (up to 100 watts), while participating in special tests organized or sponsored by the Radio Society of Great Britain. The tuning conditions enforced in all cases are tantamount to the use of crystal control, or of a wavemeter used in conjunction with a crystal.

Amateur transmitting licenses are not issued unless the applicant appears to be a genuine experimenter and capable of installing and working his proposed apparatus. The use of an open aerial is prohibited where the suggested experiments do not justify it, e.g., experiments in connection with methods of modulation. Although telephony is authorized, all licensees or their named operators must be able to receive and send messages in Morse at not less than 12 words per minute.

Frequency Measurement.

A short wave check station has been erected near St. Albans, (14 miles from London). This station is used solely as a frequency measuring station covering between 10 and 200 meters. It is equipped with a tuning fork controlled multivibrator, and is able to give an extremely accurate measurement of the frequency of any station which is working off wave, and consequently causing jamming on any service. It is also of assistance in checking the wavelengths of amateur transmitters. At the same site a short wave direction finding station is being installed. A second station of similar character is being equipped at Banbury, (80 miles from London).

Mobile Receivers.

To assist in the detection of oscillation and electrical interference, motor vans equipped with receivers and loop aerials are used. Officers engaged in the investigation of interference cases are equipped with portable receivers, built for telephone reception only. Self-contained plug-in frames enable listening to be carried out on both broadcast bands, and also on the upper amateur transmitting band. The receivers are particularly accurate as regards direction, as shown by the frame position. They will function equally well using an aerial and earth, and thus give an immediate check on the operation of a complainant's set. A complete receiver with batteries, 3 frames, waterproof cover, and turntable weighs 23 lbs.

Emergency Services.

Telegraph facilities in the British Isles are extended to upwards of 50 islands around the coasts by means of submarine cables from the mainland.

The majority of such islands are located around the rugged coast of Scotland, and it occasionally happens that communication between the islands and the mainland becomes cut due to a faulty submarine cable.

The repair of a cable cannot always be undertaken immediately but depends upon the location of the cable repair ships at the time of breakdown, the weather conditions, and upon the urgency of the work in hand. The majority of the cable failures can be attributed to storms and consequently a number of cables may be interrupted at the same time and this may mean long periods of isolation for some islands unless an alternative to cable communication is provided. This inconvenience however, is minimized by the installation of emergency wireless apparatus.

A number of complete wireless installations are held in readiness at central points in the country for dispatch to any required site and communication is restored within a few days.

At the more important places and at those places where the traffic is of greater volume, sites have previously been arranged for and no time is therefore lost in the erection of a station. In other cases the aerial masts are left standing and time is again saved both in erection and transport of stores.

The emergency equipment consists of masts and aerial gear, petrol-engine generating set, motor alternator, switchboard, radio transmitter, and receiver.

It will be observed that each station is complete in itself and need rely on no outside source of power. However, where an electric supply is available arrangements are made to dispense with the use of the engine generator.

The masts are 80-ft. tubular steel type arranged for transport in 10-ft. lengths screwed at their ends for easy erection on site. The erection is done by means of a 30-ft. derrick constructed on similar lines to those of the mast itself. The masts are supported by 16 stays in four sets spread at right angles. The engine generator is a twin-cylinder petrol engine to which a d-c generator is direct coupled. The whole of the apparatus is transported in specially constructed cases.

Emergencies normally fall into three different classes:

(a) Erection of one station to work with an existing station.

(b) Erection of two stations for intercommunicating.

(c) Opening emergency stations, permamently installed as a precaution against cable failures.

The majority of the emergencies fall under category (a) needing the erection of only one of the emergency installations.

Under category (c) only two stations exist at present and these are brought into operation as required. These stations were installed to cover the failure of important cables where the amount of traffic to be dealt with would probably have been outside the scope of the

normal emergency equipment and where no delay in establishing communication must occur.

Some emergency cases however do not fall within any of the above mentioned categories and have to be treated specially as the occasion arises.

In concluding the review, the author would like to acknowledge the assistance he has received in its preparation from the radio staff of the Post Office, and his thanks are also due to the Postmaster General for permission to publish the details of the work.

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THE RCA WORLD-WIDE RADIO NETWORK*

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LAST October, the radio network of the RCA communication system celebrated its tenth birthday. At least we must go back to October, 1919, for the actual beginning of this vast project, or when the Radio Corporation of America began its corporate existence. Prior to that time, all transoceanic communication efforts were largely of an experimental character. Even when vast distances could be spanned by positive signals, the handling of traffic was hardly comparable with the efficient methods attained by cable companies after many decades of business usage. Transoceanic radio, while it did handle a small portion of the transoceanic telegraph traffic, had yet to gain a place in the business world.

In the decade since the Armistice, however, long-distance radio communication has made notable strides both technically and commercially. In the extent of the service it has virtually duplicated the submarine cable network, developed over half a century. Technically, it has progressed more rapidly than the submarine cable. Commercially, it has introduced new standards for telegraphic traffic by way of operating speed, accuracy, and lowered cost. The competition of radio has served to spur cable engineers and cable companies to greater technical efforts, while the public has gained the advantages of better service and lower rates. Today, the competition between radio and cable services is no longer based on rates. Rates are practically uniform. Radio, once the great experiment, now holds its own on the basis of service.

All of which serves to focus attention on the technical progress which must necessarily have been scored in transoceanic radio during the past decade, and which constitutes the subject of this paper.

In order to appraise better the progress that has been made, let us review briefly the status of transoceanic radio prior to the RCA efforts. Before the World War, three nations entertained world-wide radio communication network plans. Great Britain, despite her control of submarine cables, had a most ambitious plan known as the All-Red Chain of radio stations, whereby it was hoped to establish radio circuits between England, the far-flung British colonies, and

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other countries, covering every continent. The spans were from 2000 to 4000 miles, with the climax attained in the circuit between Vancouver and Sidney, diagonally across the Pacific, a distance of 6700 miles. The German radio network, centered on Nauen, included distances of even more ambitious proportions than the British, with a few circuits of 3000 miles, but most of them around 7000 miles. The French communication scheme centered about several French stations which were evidently intended to divide time between a number of terminal stations abroad. The spans were nothing short of fantastic, such as from France to French Indo-China, virtually half-way round the world.

Considering the actual achievements in transoceanic radio communication, from the inauguration of a service of a commercial type between Glace Bay, Nova Scotia, and Clifden, Ireland, in 1908, until the advent of the World War, these world-wide radio networks were obviously the dreams of gentlemen quite unhampered by engineering considerations. With arc, quenched gap, timed spark, and small high-frequency alternators, operating at relatively low frequencies or long wavelengths, at their disposal, their plans were far in advance of the possibilities of the radio art, as it then existed.

It remained for the World War to give transoceanic radio communication a severe test, due to the urgent need for transoceanic communication facilities not only on the part of belligerent nations, but also on the part of neutrals. Our own country found itself in dire need of independent transoceanic communication channels before entering the conflict, and even more so when a belligerent, with military and naval forces abroad with whom contact had to be maintained.

Just prior to the World War, the British Marconi Company and the General Electric Company had discussed the need in long-distance radio communications of a machine which would generate directly the high frequencies required for this service. The Marconi Company indicated that they would be interested in the production of a machine which would produce at least 150 kw and which could be operated continuously on telegraph load at this output.

The General Electric Research Laboratories worked out this problem and Marconi visited Schenectady for the express purpose of witnessing a shop floor test of the first Alexanderson high-power high-frequency generator.

In addition to the work on the high-frequency generator, the General Electric Company succeeded in developing a new type of antenna circuit which has been used subsequently with this generator.

An installation of this equipment was made at New Brunswick and tested out satisfactorily early in the war and during the subsequent period, a 200-kw high-frequency alternator was installed and tested. This unit was given a very practical trial in the handling of transoceanic traffic while the Versailles Conference was in session and its operation proved highly successful.

Following the Armistice, the British sought exclusive rights to the Alexanderson alternator. U. S. Government radio authorities (Admiral Bullard and Captain Hooper of the Navy Department), foreseeing a possible threat to future American communications, urged the General Electric Company, as a patriotic duty, not to make a contract granting exclusive rights to foreign interests. Subsequently, the British contract was rejected by the General Electric Company and the Radio Corporation of America was founded. Although organized in October, 1919, it was not until the following spring that the RCA organization began transoceanic operations, with the return of the radio stations to private ownership by the United States Navy which had taken over all radio facilities during the War. With the immediate facilities available, the Radio Corporation of America soon had commercial circuits in operation across the Atlantic to Great Britain, France, Germany, and Norway, and across the Pacific to Hawaii and Japan. From this modest beginning, the RCA international and domestic radio circuits have grown until they stand as follows, as of December 31st, 1929:

Transatlantic

Great Britain	Holland
Norway	Belgium
Sweden	Turkey
France	Portugal
Germany	Liberia
Poland	Italy
Spain	Syria

West Indies, Central and South America

Argentina	Porto Rico
Brazil	Curacao (D.W.I.)
Chile	Cuba
Colombia	Costa Rica
Venezuela (Maracay)	Porto Rico—New Orleans
Venezuela (Maracaibo)	Panama—New York
Dutch Guiana	Panama—San Francisco

Transpacific

Hawaii	Shanghai (via Philippines)
Japan	Hawaii—Japan
Philippines	Hawaii—Philippines
Dutch East Indies	Fiji Islands
French Indo-China	
Hong Kong (via Philippines)	

Miscellaneous

Canada (Montreal)
Australia (via Montreal)

Domestic

New York—San Francisco

The following circuits are to be opened in the near future:

U.S.—Panama
U.S.—Nicaragua
U.S.—Czechoslovakia
U.S.—Russia

It is well to note that the present radio circuits, unlike those of pre-war days, are based primarily on commercial considerations. They are established between stations of sufficient power to span the intervening distances under all conditions. Although not in the form of physical conductors between transmitting and receiving points, they are no less firmly fixed from the standpoint of traffic flow.

For the first few years of the RCA network, the Alexanderson alternator, operating at long-wave lengths, served as the foundation. Alternators were installed at Marion, Mass., Rocky Point, N. Y., New Brunswick, N. J., and Tuckerton, N. J., for the transatlantic and Latin-American circuits, and at Bolinas, Calif., and Kahuku, Hawaii, for the transpacific circuits. Because of the high cost of these transmitting units, the RCA facilities were necessarily limited to the more important overseas nations whose traffic requirements warranted high-power radio circuits. But for the rapid development of short-wave transoceanic radio technique, our world-wide radio network might still be a dream rather than a reality; for, in short wave radio, transoceanic radio communication has attained the efficiency, flexibility, low investment, and low operating costs which makes possible a truly universal service.

Skipping the many trials and tribulations, we arrive at the present time, which is the main consideration of this paper. In place of the Alexanderson alternator, once the mainstay of transoceanic radio,

the RCA network comprises a preponderance of short wave vacuum tube transmitting units. Nevertheless, the Alexanderson alternators continue to provide communication facilities of unequaled steadiness and reliability. It so happens that the traffic load has increased at such a rapid pace that it has been quite impractical to build and install the requisite short wave equipment. During the recent interruption of transatlantic cable services due to earthquake disturbances, the Alexanderson alternators played an important part in handling the extra volume of traffic diverted to the radio channels.

Transatlantic radio circuits are mainly centered at Rocky Point, some 70 miles east of New York City, near the north shore of Long Island. On the large tract of land purchased some ten years ago by the Radio Corporation of America, there have been installed the two original long-wave antennas for the Alexanderson alternators, a complete British Marconi beam, and about a half-hundred RCA short-wave projector and nondirectional antennas. Two large power houses contain the transmitting units which maintain the radio circuits to European, Latin-American, and West Indian points. There are at present nineteen short wave transmitters installed at Rocky Point, and more units are being added. The short-wave transmitters are mostly of 20–40 kw rating, operating at 40 kw on the lower frequencies and 20 kw on the higher frequencies. Most of the transmitters are arranged to operate on two or more frequencies, so that they may be employed effectively at different times of the day and seasons of the year.

At New Brunswick, N. J., there are two Alexanderson alternators and three short-wave transmitters. Present plans include the enlarging of this station so that it may eventually equal Rocky Point. The economic limit of size of the latter station is being rapidly approached, hence, future expansion of transatlantic radio facilities may be centered at the New Brunswick site. A new power house at Rocky Point, just completed, will house fourteen additional short wave transmitters. A development building will contain experimental equipment which may be developed, installed, and operated without interfering with regular services.

At Marion, Mass., on Cape Cod, is located a combined transatlantic and marine service station. The present equipment consists of two Alexanderson alternators for transatlantic service, two medium-wave transmitters and one short wave transmitter for ship service. Additional long-wave and short wave marine service facilities are being provided.

The Tuckerton, N. J., station includes two Alexanderson alterna-

tors for transoceanic service, and several vacuum tube transmitters employed in marine communication services.

Radio traffic across the Pacific to Hawaii and to the Far East is handled in San Francisco by remote control through transmitters installed at Bolinas, Calif. At that point there are two Alexanderson alternators and eleven short wave transmitters. Considerable construction has been in progress of late at Bolinas, making of this station a radio central comparable with Rocky Point.

An important link in the Pacific radio circuits is Kahuku, in Hawaii, which is equipped with two Alexanderson alternators, a high power long wave vacuum tube transmitter and several short wave transmitters. Until recently, Hawaii was a relay point for transpacific traffic, but with the development of short wave transmission the traffic with most of the Far East points is now handled directly from San Francisco.

The newest short wave installations are of the directional type, so designed that signals may be accurately aimed at the receiving point. Many short wave transmitters are also operating on half wave antennas or doublets. The doublet antenna is not appreciably directional thereby affording greater coverage at the sacrifice of concentration. A large number of short wave transmitters employ the RCA projector antennas which embody the latest developments in short wave energy concentration. The RCA projector antenna is arranged with two, three, or four bays, for this purpose.

It is the remarkable flexibility of the RCA transmitting facilities that has made possible the early realization of a universal communication system. A given short wave transmitter may be assigned to a plurality of circuits during the 24 hours of the day. In fact, the assigning of transmitters to different circuits has been reduced to a strictly engineering basis, consistent with traffic requirements, and this important work takes up the full time of a competent engineer. The frequencies employed for a given short wave circuit must be changed at different periods of the day, due to the varying skip distance, as well as for different seasons of the year. These factors are fully established and charted, so that frequencies are changed with the same precision and routine as a train dispatcher moving trains in and out of a large terminal. By way of example, we know today that frequencies above 16,000 kc are practically useless between stations in darkness. From 12,000 to 16,000 kc is the frequency band best suited for part daylight transmission. Below 11,000 kc are the frequencies best suited for night operation. These facts apply to the transatlantic circuits. If we turn to shorter or to longer distances, the frequencies

require modification. The higher the frequency, the greater the skip distance; and if the frequency is increased sufficiently, the waves sikp off the earth entirely and fail to return. In certain high-frequency transmitting tests the signals could not be intercepted except by means of an airplane with a consequently greatly elevated antenna.

The short wave transmitters are arranged usually for daily operation on two different frequencies. The change in frequency is accomplished by quick switching between predetermined taps on the coil systems of the amplifiers in conjunction with switching between the precision crystal frequency control units.

Some circuits employ three or four transmitters for their traffic, while others make use of a single or common transmitter at different times of the day, working on a time schedule arranged by the traffic men. This flexibility of operation insures for radio the necessary peak load facilities on the one hand, and, on the other, the ability to take care of the relatively small traffic requirements of nations heretofore neglected in the scheme of inflexible cable communications or even high power radio.

The receiving facilities of the RCA network are located at Riverhead, L. I., for the New York traffic office, and Marshall, Calif., for the San Francisco traffic office. The Belfast station on the coast of Maine, was employed for a time as a stand-by station in handling long-wave traffic. At such times as static was most troublesome in the vicinity of Riverhead, the Belfast station handled the incoming signals which were transferred over direct wire to the New York City office. However, due to relative freedom from static on short waves, the Belfast station has been closed.

Although static is no longer a factor in transoceanic radio work utilizing short waves, fading of various kinds constitutes the present problem. There are seasonal, sunlight, and darkness fadings, which are circumvented by the assignment of the most desirable frequency found through long experience. While static disturbances are highly damped, at the higher frequencies they are relatively weak, so that there is less apparent static on short waves than on broadcast, marine, and longer waves. There is also short fading to contend with, or fading occurring in periods of less than a minute, during which the signal strength drops from full amplitude to practically zero. This variety of fading is being mastered by means of the diversity receiving system, which is based on the fact that short fading does not occur simultaneously at three antennas set a given distance apart. The RCA receiving stations now employ the diversity system, usually with three antenna groups for a single unit, although two groups can also

be employed. No more than three groups are required for satisfactory results. The groups of antennas comprising the complete diversity antenna system, are spaced approximately 1000 ft. apart, and are connected by radio-frequency transmission lines to the receivers, which are arranged to deliver a virtually constant signal output, thereby overcoming short fading.

The system of centralized control and operation of international radio communication services was originated and developed by RCA. The Central Radio Office in New York City was the first commercial radio system to be so equipped and operated. By this means a large number of transmitters, widely separated as regards physical location, are controlled from a central city office, thus assuring extreme flexibility and increased efficiency in their assignment and use. In reception also, instead of separate receiving stations each with its own staff of operators and the necessity of relaying traffic to the terminal point by means of telegraph lines, one central receiving station now handles all incoming signals and transfers them automatically to the city office over the special tone channels. Thus all actual operation is accomplished in one office, with resultant improved service, concentrated supervision, and economical operation.

The volume of traffic handled on many of the RCA circuits is extremely heavy, and it is frequently necessary to operate two or more transmitters simultaneously to the same country, depending on the respective traffic loads of the various circuits. For the same reason most of the European countries with which RCA communicates, have two or more transmitters available, so that New York often receives simultaneously no less than thirty separate signals over as many radio channels.

The New York traffic office, and likewise that of San Francisco, is connected to the remote transmitters and receivers by means of six direct telephone lines. The longest line is to the Marion, Mass., station, or 245 miles. Tone channels, by means of carrier currents of different frequencies, are established over these direct telephone lines. If the telephone circuit has a substantially flat characteristic up to 2200 cycles, ten tone channels can be obtained. It is usual to simplex these telephone lines, as in ordinary telegraph service, so as to obtain a channel for service messages. It is possible to operate ten transmitters by means of a single pair of telephone wires and tone control. Present plans are to operate transmitters by means of tone control directly up to the oscillator, thus doing away with all mechanical relays. Heretofore, the relays have constituted a serious obstacle in attaining higher operating speeds. With their elimination, further

progress can be made in the way of higher signaling speeds. Also, an added measure of reliability is gained.

It is in the handling of traffic that the technical advances are most apparent to the general public. In 1920, hand copying was the rule. Receiving was a tiresome routine, with the operator wearing earphones and copying weak and fluctuating signals with paper and pencil. Sending was by hand at first, and later by automatic sender. It had generally been held that the clicking of the typewriter would interfere with the reading of the signals. However, as signal strength and reliability improved reception direct on the typewriter was tried and the experiment was successful. Other operators began using typewriters, and the pencil and paper operator passed out of the radio picture.

Later came the automatic recorder, after the dictaphone had been tried for high-speed reception, with signals recorded on the wax record at high speed, and then slowed down for transcription by an operator. Two automatic recorders appeared at about the same time, namely, that which recorded the signals in the form of a continuous wavy line on a moving paper tape, and that which recorded signals photographically on a strip of paper. The former, because of its sturdy construction and simplicity of operation, became the standard recorder and has been in use for practically a decade with little change.

From the beginning, the RCA operators were placed in a large traffic room and trained to operate irrespective of surroundings, dozens of operators working at top speed in one large room, disregarding surrounding noises and the hustle and bustle of traffic, handling transatlantic radio messages in a businesslike manner.

The introduction of the typewriter has had a marked influence on the accuracy of radiograms. Particularly in handling code words the accuracy of which cannot be determined by the mere context, hand copying lent itself to many errors. With the introduction of the typewriter, together with a permanent record of the transmitted traffic in the form of the perforated tape, and the received traffic in the form of the recorder tape, mistakes were reduced to an absolute minimum, and it became possible to check back any radiogram.

Today, hand operation is practically unknown. Everything is automatic. All RCA circuits are duplex operated, but for convenience of supervision and distribution of traffic, several transmitter controls are concentrated on one table irrespective of the circuits to which they may be assigned. Each sending operator manipulates a standard keyboard perforator from which the perforated tape is fed into a Wheatstone transmitter automatically controlling a remote

transmitter. A speedometer attachment on the Wheatstone transmitter permits the operator to adjust his transmission to any speed desired by the overseas station, which in practice may range from 25 to 225 words per minute, with 100 considered the economical ideal. As soon as the transmission of the radiogram is completed, the exact time of transmission is recorded on the message blank by means of an automatic time stamp. Transmission is continuous, as any requests from the distant station pertaining to traffic are forwarded without stopping the circuit.

In the reception of radiograms from European and South American points, incoming signals are detected and amplified at the RCA Central Station at Riverhead, L. I., and automatically transferred over tone channels to New York City, to operate the RCA standard ink recorder. The moving tape passes in front of the receiving operator, who, with a typewriter, transcribes the signals directly on to a radiogram blank in duplicate. One operator is usually able to transcribe up to 50 or 60 words per minute by this method, but when the distant station is sending above this speed, additional operators are assigned to special transcribing positions conveniently located on the high-speed receiving table.

As fast as they are transcribed, the radiograms are placed on a belt conveyor which deposits them at a central point where they are timed, routed, and numbered according to destination, enveloped, and dropped into a chute connecting with the messenger room whence they are immediately sent out for delivery. Such radiograms as are destined to New York and which bear code addresses, however, must first be "unpacked" from the file of registered code addresses numbering many tens of thousands, and this is done prior to their dispatch to the messenger room and before being enveloped. Radiograms destined to interior points of the United States, except Washington and Boston, are transferred to the telegraph companies for ultimate delivery.

From the engineering end, the operating speed is developed to the highest possible standard, so that the traffic end may use such speeds as are deemed best. The preferred operating speed today is 100 words per minute, although perfectly legible tape is obtained at speeds up to 225 words per minute. Both in the matter of transmitting and receiving, the American terminal facilities compare very favorably with those of our overseas correspondents.

RCA rates were originally lower than corresponding cable rates, due to technical facilities and advantages in the matters of initial investment and operating costs. However, the radio rates were met

by the cable companies in 1923, and since then both radio and cable rates have been practically the same. Today, radio competes on the basis of service and not on price.

In addition to the RCA transoceanic circuits, there is the important marine network, operated by the Radiomarine Corporation of America, with fourteen powerful land stations handling traffic for transatlantic, coastwise, transpacific, and Gulf shipping, as well as the shipping on the Great Lakes. This network is also handling aircraft radio communications to a considerable extent for the present, particularly in conjunction with transoceanic flights.

As a forerunner of what may be expected by way of transcontinental and intercity radio networks, the RCA network recently added the New York-San Francisco circuit, which is handling a steady flow of traffic daily in competition with telegraph circuits. With the granting of the necessary additional channels, the RCA network may yet be expanded so as to include circuits to all important centers in this country, joining them directly with the New York and San Francisco focal points of transoceanic radio traffic.

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AN ELECTRON TUBE WATTMETER AND VOLTMETER AND A PHASE SHIFTING BRIDGE*

By

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Summary—*The purpose of this paper is to describe a wattmeter, for measuring power of a few microwatts or more, a phase shifting bridge for controlling the angular relation of two potentials without changing their amplitudes, and a voltmeter for measuring potentials of a few millivolts without amplifying.*

Electron Tube Wattmeter

A WATTMETER for small power should have the following characteristics: high sensitivity without seriously modifying the circuit being measured, high accuracy, linear scale, range easily variable, and calibration independent of frequency.

These specifications are largely met by the balanced modulator type of electron tube wattmeter shown in Fig. 1.

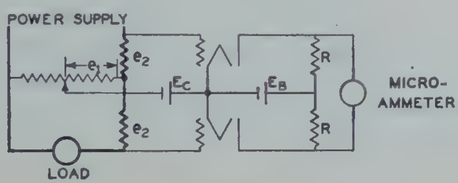

Fig. 1

The theory of its operation is essentially the same as the usual grid modulator except that both components of the input voltages are of the same frequency. One component, proportional to the load current, is obtained from a resistance of low value inserted in series with the line, and the other, proportional to the load voltage, from a high resistance connected across the line. The loss in the series element is quite small as compared with the load while that of the shunt element may be made negligible by increasing the shunt resistance. The sum of the instantaneous values of the two component voltages is impressed on the grid of one tube and their difference on that of the other. The function of the balanced modulator arrangement is to eliminate undesired components from the indicating instrument, usually a direct-current microammeter, which measures

* Dewey decimal classification: 621.374.6×R243.1×R241.5. Original manuscript received by the Institute, June 2, 1930.

directly the power supplied to the load, as will be evident from the following analysis.

It is well known that when operating on the curved portion of the plate characteristic the plate current is approximately proportional to the square of the voltage. Over the range for which this holds

$$i=k[E+\mu(e_1+e_2)]^2 \tag{1}$$

where $E=E_b-\mu E_c, E_b$ and E_c are the constant voltages of the plate and grid circuits and e_1 and e_2 the instantaneous values of the two components previously mentioned. The current in the plate circuit of one tube is

$$i'=k[E^2+2\mu E(e_1+e_2)+\mu^2 e_1^2+\mu^2 e_2^2+2\mu^2 e_1 e_2] \tag{2}$$

and that of the other is

$$i''=k[E^2+2\mu E(e_1-e_2)+\mu^2 e_1^2+\mu^2 e_2^2-2\mu^2 e_1 e_2] \tag{3}$$

Assuming, for the time being, that the tubes have similar characteristics and equal external plate resistances the microammeter reading is proportional to

$$i'-i''=k[4\mu E e_2+4\mu^2 e_1 e_2] \tag{4}$$

all other components are eliminated by the balanced arrangement.

Assuming the input components to be sine waves differing in phase by ϕ degrees, determined by the load power factor, then the current, i, through the instrument is

$$i=k[4\mu E E_2 \sin \mathrm{wt}+4\mu E_1 E_2 \sin \mathrm{wt} \sin (\mathrm{wt}+\phi)] \tag{5}$$

Since the average value of a sine wave is zero the first term will not produce a reading on the direct-current instrument. Therefore, only the last term need be considered. Substituting for the product of the sines gives

$$i=2k\mu E_1 E_2[\cos \phi-\cos(2\mathrm{wt}+\phi)] \tag{6}$$

The average of the last term over a cycle is zero and the reading is proportional to

$$E_1 E_2 \cos \phi.$$

Thus, the instrument may be calibrated to read directly the power supplied to the load, and since $E_1E_2 \cos \phi$ is proportional to power it is evident that the scale is linear. By circuit adjustment it is possible to secure a convenient scale factor so a calibration curve is unnecessary, but this is accomplished at the expense of sensitivity and may not be feasible.

Where harmonics are present in the load voltage and in the load current the component potentials take the form

$$e_1 = E_1 \sin \mathrm{wt} + E_n' \sin \; n \; \mathrm{wt}$$
$$e_2 = E_2 \sin (\mathrm{wt} + \phi) + E_n'' \sin (n \, \mathrm{wt} + \theta)$$

and when substituted in (4) it will be found that only the products of like frequencies contribute to the reading of the instrument. Therefore, it measures correctly the total power. Where a given harmonic appears only in the load voltage or load current no power is involved and it produces no deflection of the microammeter pointer.

In the foregoing discussion a quadratic law was assumed. The range over which this holds may be easily found experimentally. The theory applies equally well for the three halves power law.

While it is highly desirable to use matched tubes if possible, compensation for slight differences in tube characteristics may be effected by employing different values of resistance in the plate circuits or different grid biases.

The range of the wattmeter is determined by the total allowable grid input voltage which is controlled by the series and shunt resistance elements. The instrument has been used to measure less than twenty microwatts and there is no reason why it could not be used for considerably smaller values. Its sensitivity is best described in terms of input volts squared to produce a given current through the indicating microammeter. For UX-250 tubes this value is less than 0.03 volts^2 per microampere. Thus if 10 volts were applied to the load a series drop of 3 millivolts would be required. For many purposes 201–A or similar tubes may be used to advantage. The frequency range is limited only by the interelectrode capacity of the tubes.

The circuit diagram in Fig. 1 shows that the wattmeter measures the power dissipated in the half of the series element adjacent to the load, which corresponds to the loss in a dynamometer wattmeter when the voltage element is connected on the power side of the current coil. For most cases the loss in the series element will be negligible but for measurements where the power factor is low may require correction. There is a second loss caused by the current of the shunt element flowing through the upper half of the series element. However, this may be made negligible by increasing the shunt resistance which is used merely to obtain a grid potential without drawing any current.

When measuring power it is sometimes desirable to determine the voltage applied to the load which may be accomplished by throwing the switch in Fig. 2 to V. The function of the resistance r is to maintain the bias on the upper tube when switching from W to V, so as

not to damage the microammeter, without short-circuiting the alternating voltage that is impressed upon this tube. The upper tube is used for balancing purposes so the indicating instrument will read zero when no voltage is being measured. The scale is, of course, quadratic. In this and many other electronic voltmeters there are two basic defects: lack of sensitivity when measuring small voltages and the

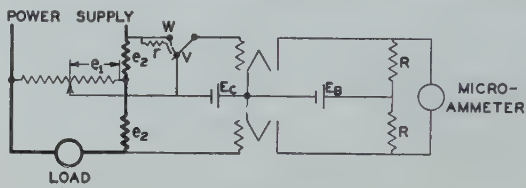

Fig. 2

quadratic nature of the scale, both of which are due to the fact that the indications are proportional to the square of the input voltage. A less serious matter is the necessity of employing an opposing battery to permit the use of a sensitive instrument with consequent hazards.

However, greatly increased sensitivity and a linear scale is possible with a balanced modulator type voltmeter and a phase shifting bridge which will now be described.

Phase Shifting Bridge

Two alternating-current bridges together with their corresponding vector diagrams are shown in Fig. 3, the first a balanced bridge having equal ratio arms and the second an inverted or phase shifting bridge obtained by interchanging the lower elements of the balance bridge.

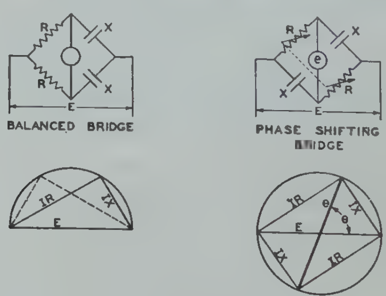

Fig. 3

In the balanced bridge the output voltage is zero while in the phase shifting bridge it is equal in magnitude to the input voltage, their phase relation being controlled by varying simultaneously the two resistances or the two capacities. This phase shifter may be used with potentially operated devices where no current is drawn from the output terminals of the bridge.

Balanced Modulator Type Voltmeter

The increased sensitivity of the voltmeter is obtained by the use of a relatively large auxiliary voltage, of the same frequency and preferably from the same source as the voltage being measured, which is brought into phase with it by means of the phase shifting bridge. The auxiliary voltage from the output terminals of the bridge is connected in the common grid lead of the balanced circuit, a particular application of which is shown in Fig. 4 where a small voltage between the points A and C is being measured.

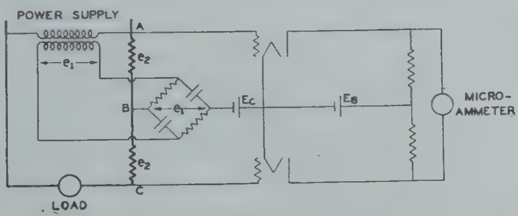

Fig. 4

As in the case of the wattmeter the reading is given by (7) but in this case ϕ is reduced to zero by the phase shifting bridge, $\cos\phi = 1$, so the reading is proportional to the product of the unknown and auxiliary voltages. From the form of the equation it is evident that the positions of the two voltages are interchangeable permitting various circuit arrangements.

The in-phase relation is easily determined experimentally as it is indicated by the maximum deflection for a given voltage. Since the auxiliary voltage is maintanied constant over a given range a linear scale is obtained which is highly desirable. When measuring small voltages the sensitivity may be one hundred times that of the usual type.

So far the operation has been limited to the curved portion of the plate characteristic, however, in the case of the voltmeter it is possible to extend it to the linear part. When used in this manner it is similar to power detection in which e_1 corresponds to the carrier and e_2 to the signal of ordinary radio reception. When used in this manner the sensitivity depends upon $dI_p/dE_g = G_m$ rather than upon d^2I_p/dE_g^2 as in the previous case.*

Note Added:

After the independent development of this balanced modulator type electron tube wattmeter, it came to the authors' attention that Patent 1,586,553 issued June 1, 1926, to E. Peterson of the Bell Telephone Laboratories covers an identical circuit.

* Stuart Ballantine, "Detection at high signal voltages: Part I, Plate rectification with the high Vacuum Triode," Proc. I. R. E., 17, 1153; July, 1929.

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ON THE MAGNETRON OSCILLATION OF NEW TYPE*

BY

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Summary—*In this paper the experimental results pertaining to the magnetron oscillation of new type is chiefly given.*

Comparatively intense oscillations of 10 centimeters order in wavelength were successfully produced.

INTRODUCTION

IN another communication[1] the author pointed out that we could produce very short wavelength oscillations of two different types with a magnetron. These two types were (A) the oscillation whose frequency is approximately independent of the external circuit, and (B) the one whose frequency depends principally on the external circuit. The oscillation of the latter case has not been reported by others so far as the author knows, so that the details regarding this will be dealt with in this paper.

EXPERIMENTAL RESULTS

The magnetron oscillations of (A) and (B) types could be obtained separately with a small magnetron when a very high voltage was applied to the anode. The intensity of the applied magnetic field, the amount of filament heating, and the voltage applied to the anode, which were fit for the maintenance of the (B) type oscillation, were slightly different from those which were fit for the maintenance of those of the (A) type.

One of the experimental results, which was obtained with a small magnetron (the diameter of the anode$\doteqdot$0.3 cms), is shown in Figs. 1 and 2. In the figures, V_a, I_a, I_h, and λ represent the anode voltage, the anode current, the field coil current, and the wavelength, respectively. I_d and x represent the detector current and distance through which the short circuit condenser was shifted along parallel wires. The oscillation shown in Fig. 1 was type (A) and the one shown in Fig. 2 was type (B). As seen from the figures, the wavelength of the oscillation of type (B) was many times longer than that of type (A). The intensity of the oscillation of type (B) was also very many times stronger than that of type (A). Similar results were always obtained when small magnetrons were used.

* Dewey decimal classification: R133. Original manuscript received by the Institute, June 3, 1930. The present research was carried out in Tohoku Imperial University, Sendai, Japan.

[1] Kinjiro Okabe, "On the short wave limit of magnetron oscillations," PROC. I. R. E., **17**, 652; April, 1929.

Discussion

The oscillation of type (A) and that of type (B) may correspond to the Barkhausen-Kurz type oscillation and the Gill-Morrel type oscillation in the case of a triode, respectively. It may be, however, noteworthy that the wavelengths of the oscillations of type (B) are much longer than that of type (A). In the case of Gill-Morrel type oscillations the wavelengths are always shorter than that of the pure Barkhausen-Kurz type one, if the conditions are similar in both cases.[2]

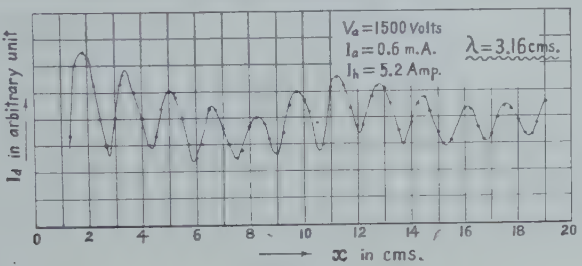

Fig. 1

Next, it may be also noteworthy that the intensity of the oscillation of type (B) is comparatively intense. The maximum value of I_d in Fig. 2 is about a thousand times larger than that in Fig. 1. Intense oscillations of 10 centimeters or so in wavelength could be steadily obtained by this method.

The existence of a negative resistance is very probable in the present case. This may be the cause of the oscillations of type (B).

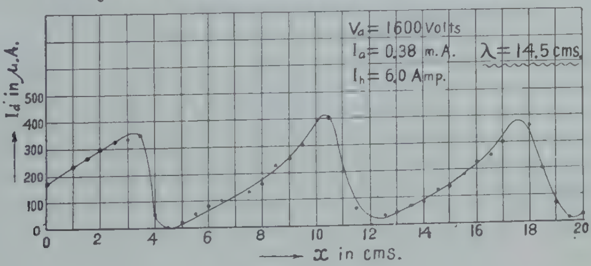

Fig. 2

The wavelength 3.16 cm. shown in Fig. 1 was the shortest one in the fundamental oscillations which could be obtained stably by means of a magnetron. The author could detect, however, an unstable fundamental oscillation of 2.8 cm in wavelength in the course of the present research.

[2] H. E. Hollmann, *Jahrb. d. drahtl. Tel.*, February, 1929.

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VARIATION OF THE INDUCTANCE OF COILS DUE TO THE MAGNETIC SHIELDING EFFECT OF EDDY CURRENTS IN THE CORES*

By

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Summary—*An analysis is made of the shielding effect of eddy currents on the flux in the interior of cores of cylindrical or flat sheet material. It is shown that the counter voltage of self inductance of an iron-cored coil is due only to the component of flux in the core which is in phase with the flux at the surface of the core. Expressions are obtained and curves plotted showing the variations of inductance of a coil with frequency, or with the conductivity and permeability of the core material. Sample calculations and some experimental results are given. The results show that the inductances at high frequencies are actually less than the predicted values, which leads to the suspicion that some factor other than eddy currents causes the flux in the interior of the cores to decrease with increasing frequency.*

Introduction

It is well known that if a sinusoidal electromotive force is impressed upon a cylindrical or sheet conductor, the current density will not be uniform throughout the body of the conductor, but will vary from the surface to the center in a manner which depends upon the frequency of the impressed e.m.f. and upon the magnetic permeability and electrical conductivity of the conductor material. Similarly if a sinusoidal electromotive force is impressed upon a coil enclosing a core of cylindrical or sheet material, the magnetic flux density within the core will vary in the same manner and with the same quantities as the current density in the electrical case.

These phenomena are probably best known as "skin effect" in the case of conductors, and as the "shielding effect of eddy currents" in the case of cores. The equations for current density or flux density are identical in form for either wires or sheets, whence the current distribution in conductors varies in the same manner as the flux distribution in cores. However, in the case of conductors, we are chiefly interested in the crowding of the current to the outer layers of the conductor as it affects the resistance losses in the conductor, while, in the case of cores, we are interested in the flux distribution in the core as it modifies the resistance losses in the core and the inductance of the coil surrounding the core.

* Dewey decimal classification: R145.3. Original manuscript received by the Institute, May 29, 1930. Presented before Fifth Annual Convention of the Institute, August 20, 1930.

The latter phase of the shielding effect of eddy currents is one of considerable interest in view of the widespread use of induction coils, transformers, and other electromagnetic apparatus, particularly in the field of electrical communication. Accordingly, it is proposed to develop the relationships which have a bearing on the design of coils having cores of magnetic or conducting materials.

Notation

The following notation will apply throughout the rest of the discussion.

B = the magnetic flux density (in maxwells per square centimeter) at any point within the core material.

x = the distance (in centimeters) from the axis of the cylindrical core, or the mid-plane of the flat sheet of core material.

B_x = the value of B at the point x.

B_s = the value of B at the surface of the core.

$j = \sqrt{-1}$

$c = \sqrt{8\pi^2\mu\gamma f 10^{-9}}$

μ = the magnetic permeability of the core material in maxwells per square centimeter per gilbert per centimeter.

γ = the electrical conductivity of the core material in ohms per cubic centimeter.

N = the number of turns in the coil.

L = the inductance of the coil, in henries.

L_0 = the inductance of the coil without eddy currents in the core, in henries.

I = the current in the coil.

f = the frequency of the impressed magnetomotive force in cycles per second.

a = the radius of the cylindrical core, or half thickness of the sheets, in centimeters.

s = the skin thickness of the core material in centimeters

$$= \frac{5030}{\sqrt{\mu\gamma f}}$$

Mathematical Development

The differential equation applicable to the core of circular cross section is[1]

$$\frac{d^2B}{dx^2} + \frac{1}{x}\frac{dB}{dx} - jc^2B = 0 \tag{1}$$

[1] Davis and Burch, "Theory of Eddy Current Heating," Ernest Benn, Ltd.

while for the flat sheet we have[2]

$$\frac{d^2B}{dx^2} - jc^2B = 0. \tag{2}$$

Equation (1) is known as Fourier's equation. Its solution for the present case, with the arbitrary constants evaluated, is

$$B_x = B_s \frac{J_0(\sqrt{-j}cx)}{J_0(\sqrt{-j}ca)} \tag{3}$$

in which J_0 is the zeroth order Bessel's function of the first kind. This may be written as follows, using the relation $J_0(\sqrt{-j}cx) = \text{ber}\,(cx) + j\,\text{bei}\,(cx)$.

$$B_x = B_s \frac{\text{ber}\,(cx) + j\,\text{bei}\,(cx)}{\text{ber}\,(ca) + j\,\text{bei}\,(ca)} \tag{4}$$

or, substituting $\sqrt{2}/s$ for c, we have

$$B_x = B_s \frac{\text{ber}\,\dfrac{\sqrt{2}x}{s} + j\,\text{bei}\,\dfrac{\sqrt{2}x}{s}}{\text{ber}\,\dfrac{\sqrt{2}a}{s} + j\,\text{bei}\,\dfrac{\sqrt{2}a}{s}} \tag{5}$$

The corresponding solution of (2) is

$$B_x = B_s \frac{e^{x/s}\left(\cos\dfrac{x}{s} + j\sin\dfrac{x}{s}\right) + e^{-x/s}\left(\cos\dfrac{x}{s} - j\sin\dfrac{x}{s}\right)}{e^{a/s}\left(\cos\dfrac{a}{s} + j\sin\dfrac{a}{s}\right) + e^{-a/s}\left(\cos\dfrac{a}{s} - j\sin\dfrac{a}{s}\right)} \tag{6}$$

in which the main and reflected wave terms are apparent, or we may write

$$B_x = B_s \frac{\cosh\dfrac{x}{s}\cos\dfrac{x}{s} + j\sinh\dfrac{x}{s}\sin\dfrac{x}{s}}{\cosh\dfrac{a}{s}\cos\dfrac{a}{s} + j\sinh\dfrac{a}{s}\sin\dfrac{a}{s}} \tag{7}$$

which is a form more suitable for further analysis.

[2] C. P. Steinmetz, "Transient Electric Phenomena and Oscillations," McGraw-Hill Publishing Co., New York.

Rationalizing (5) and (7) so they will be in the form $\alpha + j\beta$ results in a clearer picture of the phenomena. The resulting equations are

$$B_x = B_s\left(\frac{\operatorname{ber}\frac{\sqrt{2}a}{s}\operatorname{ber}\frac{\sqrt{2}x}{s} + \operatorname{bei}\frac{\sqrt{2}a}{s}\operatorname{bei}\frac{\sqrt{2}x}{s}}{\operatorname{ber}^2\frac{\sqrt{2}a}{s} + \operatorname{bei}^2\frac{\sqrt{2}a}{s}} + j\frac{\operatorname{ber}\frac{\sqrt{2}a}{s}\operatorname{bei}\frac{\sqrt{2}x}{s} - \operatorname{bei}\frac{\sqrt{2}a}{s}\operatorname{ber}\frac{\sqrt{2}x}{s}}{\operatorname{ber}^2\frac{\sqrt{2}a}{s} + \operatorname{bei}^2\frac{\sqrt{2}a}{s}}\right) \tag{8}$$

and

$$B_x = B_s\left[\frac{\cosh\frac{a}{s}\cos\frac{a}{s}\cosh\frac{x}{s}\cos\frac{x}{s} + \sinh\frac{a}{s}\sin\frac{a}{s}\sinh\frac{x}{s}\sin\frac{x}{s}}{\cosh^2\frac{a}{s}\cos^2\frac{a}{s} + \sinh^2\frac{a}{s}\sin^2\frac{a}{s}} + j\frac{\cosh\frac{a}{s}\cos\frac{a}{s}\sinh\frac{x}{s}\sin\frac{x}{s} - \sinh\frac{a}{s}\sin\frac{a}{s}\cosh\frac{x}{s}\cos\frac{x}{s}}{\cosh^2\frac{a}{s}\cos^2\frac{a}{s} + \sinh^2\frac{a}{s}\sin^2\frac{a}{s}}\right] \tag{9}$$

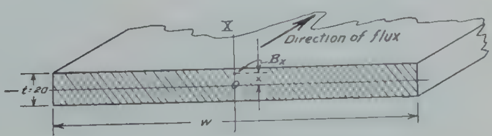

Fig. 1—Cross section of lamination.

Equations (8) and (9) show that, for both types of core, the flux in the interior is less than and lags behind the flux at the surface, the magnitude decreasing and the angle of lag increasing with the distance from the surface.

The reactive voltage in a coil wound upon an iron core must lag the total flux in the core by ninety degrees. Hence, in complex notation, if the total flux is given by $\phi_t = u - jv$, in which both u and v are real and positive, then the counter voltage induced in the coil by the total flux in the core will be proportional to

$$-j(u - jv) = -(v + ju). \tag{10}$$

For the case of both types of cores, ϕ_t is to be evaluated from the equation

$$\phi_t = \int B_x dA \tag{11}$$

in which A is the cross section of the core, and the result, in both cases, is the form $u-jv$, with the flux density at the surface of the core as the reference vector. Since the flux density at the surface of the core is

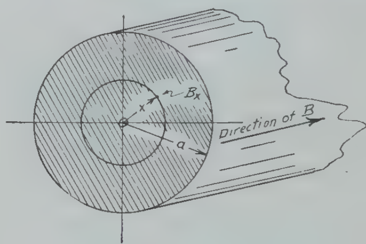

Fig. 2—Cross section of round core.

in phase with the current in the coil, the total flux in the core has a component which is in phase with the current in the coil and another component which lags the current by ninety degrees. It follows that

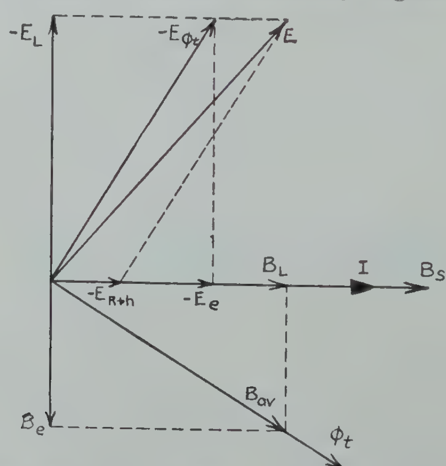

Fig. 3—Vector diagram of voltage, current, and flux in iron-cored coil.

E = Voltage impressed on coil.
I = Current through coil.
B_e = Component of B_{av} producing eddy current voltage drop E_e.
B_L = Component of B_{av} producing reactive voltage drop E_L.
E_{ϕ_t} = Total counter voltage of the flux in the core.
ϕ_t = Total area of core times B_{av}.
B_s = Flux density at surface of lamination = B_x at $x=a$.
B_{av} = Average flux density in lamination.
E_e = Eddy current voltage drop.
E_L = Reactive voltage drop.
E_{R+h} = ohmic resistance and hysteresis voltage drops.

the counter voltage induced in the coil by the total flux has a component opposite in phase to the current in the coil and a component lagging the current by ninety degrees. The first component of voltage represents an equivalent resistance drop in the coil, attributable to the power consumed by the eddy currents in the core. The second component of the voltage is the reactive drop in the coil. These vector relations are shown by the diagram of Fig. 3. Harmonics in the current and applied electromotive force are assumed negligible.

Further consideration reveals the fact that the terms u and v in the symbolic expression for total flux represent the summations, respectively, of the in-phase and quadrature components of the flux density in the cores over the cross sections of the cores, and that, therefore, the reactive voltage in the coil is contributed to only by the in-phase component of the flux density in the core, while the apparent resistance drop in the coil due to eddy currents is due to the quadrature component of the flux density in the core.

Bearing in mind that the value assumed by B_s is the same as that which would obtain throughout the core if there were no eddy currents, the current in the coil being the same in both cases, we can calculate the decrease in inductance of the coil due to the shielding effect of eddy currents in the following manner.

Given a current I through the coil, the flux density at the surface of the core will be B_s. If there were no eddy currents, the flux density throughout the core would equal B_s and the reactance of the coil would be equal, for a round core, to

$$X_0 = 2\pi f L_0 = \frac{2\pi f N \phi_t}{I} = \frac{2\pi^2 f N B_s a^2}{I}. \tag{12}$$

If eddy currents are present, the reactance will be

$$X = 2\pi f L = \frac{2\pi f N \phi_t(\text{real})}{I} = \frac{2\pi f N}{I} \int B_x(\text{real}) dA \tag{13}$$

in which B_x (real) is the real part of (8)

Dividing (13) by (12) we get

$$\frac{L}{L_0} = \frac{1}{\pi a^2 B_s} \int B_x(\text{real}) dA. \tag{14}$$

Continuing with the circular core, (14) becomes

$$\frac{L}{L_0} = \frac{2 \operatorname{ber} \frac{\sqrt{2}a}{s}}{a^2\left(\operatorname{ber}^2 \frac{\sqrt{2}a}{s} + \operatorname{bei}^2 \frac{\sqrt{2}a}{s}\right)} \int_0^a x \operatorname{ber}\left(\frac{\sqrt{2}x}{s}\right) dx$$
$$+ \frac{2 \operatorname{bei} \frac{\sqrt{2}a}{s}}{a^2\left(\operatorname{ber} \frac{2\sqrt{2}a}{s} + \operatorname{bei} \frac{2\sqrt{2}a}{s}\right)} \int_0^a x \operatorname{bei}\left(\frac{\sqrt{2}x}{s}\right) dx \tag{15}$$

and (15) reduces to

$$\frac{L}{L_0} = \frac{\sqrt{2}s}{a} \frac{\operatorname{ber} \frac{\sqrt{2}a}{s} \operatorname{bei}' \frac{\sqrt{2}a}{s} - \operatorname{bei} \frac{\sqrt{2}a}{s} \operatorname{ber}' \frac{\sqrt{2}a}{s}}{\operatorname{ber}^2 \frac{\sqrt{2}a}{s} + \operatorname{bei}^2 \frac{\sqrt{2}a}{s}}. \tag{16}$$

In (16)

$$\operatorname{bei} \frac{\sqrt{2}a}{s} = \frac{s}{\sqrt{2}} \frac{d \operatorname{ber} \frac{\sqrt{2}a}{s}}{da} \text{ and } \operatorname{ber}' \frac{\sqrt{2}s}{a} = \frac{s}{\sqrt{2}} \frac{d \operatorname{ber} \frac{\sqrt{2}a}{s}}{da}. \tag{17}$$

With (16) and tables of the ber and bei functions and their derivatives we can evaluate the ratio L/L_0 for various values of a/s, which is the radius of the core expressed in terms of the skin thickness. The variation of the inductance of a coil with radius, conductivity, or permeability of the core, or frequency of current can thus be calculated, or read from a curve.

A similar process of reasoning applied to (9) gives results as follows for sheet material of width W.

$$X_0 = 2\pi f L_0 = \frac{2\pi f N \phi_t}{I} = \frac{4\pi f N B_s W a}{I} \tag{18}$$

and

$$X = 2\pi f L = \frac{2\pi f N \phi_t(\text{real})}{I} = \frac{2\pi f N}{I} \int B_x(\text{real}) dA. \tag{19}$$

Substituting in (19) the expressions for the sheet core, we have

$$2\pi f L = \frac{4\pi s f N W B_s}{I} \int_0^a \frac{\cosh \dfrac{a}{s} \cos \dfrac{a}{s} \cosh \dfrac{x}{s} \cos \dfrac{x}{s} \dfrac{dx}{s}}{\cosh^2 \dfrac{a}{s} \cos^2 \dfrac{a}{s} + \sinh^2 \dfrac{a}{s} \sin^2 \dfrac{a}{s}}$$

$$+ \frac{4\pi s f N W B_s}{I} \int_0^a \frac{\sinh \dfrac{a}{s} \sin \dfrac{a}{s} \sinh \dfrac{x}{s} \sin \dfrac{x}{s} \dfrac{dx}{s}}{\cosh^2 \dfrac{a}{s} \cos^2 \dfrac{a}{s} \quad \sinh^2 \dfrac{a}{s} \sin^2 \dfrac{a}{s}}. \tag{20}$$

Dividing (20) by (18) we get

$$\frac{L}{L_0} = \frac{s}{a} \int_0^a \frac{\cosh \dfrac{a}{s} \cos \dfrac{a}{s} \cosh \dfrac{x}{s} \cos \dfrac{x}{s}\, d\dfrac{x}{s}}{\cosh^2 \dfrac{a}{s} \cos^2 \dfrac{a}{s} + \sinh^2 \dfrac{a}{s} \sin^2 \dfrac{a}{s}}$$

$$+ \frac{s}{a} \int_0^a \frac{\sinh \dfrac{a}{s} \sin \dfrac{a}{s} \sinh \dfrac{x}{s} \sin \dfrac{x}{s}\, d\dfrac{x}{s}}{\cosh^2 \dfrac{a}{s} \cos^2 \dfrac{a}{s} + \sinh^2 \dfrac{a}{s} \sin^2 \dfrac{a}{s}}. \tag{21}$$

Finally, (21) reduces to

$$\frac{L}{L_0} = \frac{s}{2a} \frac{\sinh \dfrac{2a}{s} + \sin \dfrac{2a}{s}}{\cosh \dfrac{2a}{s} + \cos \dfrac{2a}{s}}. \tag{22}$$

Table I is calculated from (22), and in Fig. 4 is plotted the per cent decrease in inductance, $(L_0 - L)/L_0$, versus a/s. To use Fig. 4 it is necessary to calculate the skin thickness for the core material by substituting numerical values for the permeability, conductivity, and frequency in the expression

$$s = \frac{5030}{\sqrt{\pi \gamma f}}.$$

Dividing the half-thickness of the core laminations by the calculated value of skin thickness locates the abscissa of a point on the curve,

the ordinate of which is the desired value of $(L_0 - L)/L_0$. It must be remembered in using the curves that if they are to apply accurately, the flux density in the core must be such that the permeability of the core is practically constant. This means that the flux densities must be very low. Also, in case of sheet cores, the width of the sheets must be great in comparison with their thickness, or else the edge effects, which have been neglected in the derivations, will render the calculations inapplicable. In most practical cases the edge effects in sheet cores are actually negligible, but the situation is not so fortunate in regard to the permeabilities of the cores. In a great many instances the flux densities at which cores are worked are high enough that the permeabilities of the cores will vary greatly with the flux densities throughout their interior. In such cases the calculations cannot be made exact, but they may still be made to serve as a useful guide in design work.

Because of the relatively lesser importance of round cores and the fact that satisfactory tables of the ber and bei functions were not available to the author, no calculated values of L/L_0 vs a/s are given for coils with round cores.

If, instead of integrating the in-phase component of flux density from the center to the surface of the core, we had integrated the quadrature component, we would have arrived at an expression giving the ratio of the increment resistance of the coil due to eddy currents in the core to the inductive reactance of the coil calculated for full penetration. Omitting the derivation, we give the expression as follows. For round cores we have

$$\frac{\Delta R_e}{2\pi f L_0} = \frac{\sqrt{2}s}{a} \cdot \frac{\operatorname{ber}\frac{\sqrt{2}a}{s}\operatorname{ber}'\frac{\sqrt{2}a}{s} + \operatorname{bei}\frac{\sqrt{2}a}{s}\operatorname{bei}'\frac{\sqrt{2}a}{s}}{\operatorname{ber}^2\frac{\sqrt{2}a}{s} + \operatorname{bei}^2\frac{\sqrt{2}a}{s}} \tag{23}$$

and for flat sheets

$$\frac{\Delta R_e}{2\pi f L_0} = \frac{s}{2a} \cdot \frac{\sinh\frac{2a}{s} - \sin\frac{2a}{s}}{\cosh\frac{2a}{s} + \cos\frac{2a}{s}}. \tag{24}$$

Calculations and a curve computed from (24) are given in Table I and Fig. 4. It is to be noticed that the curve has a maximum at a

value of a/s of approximately $3\pi/8$. This fact is of significance in connection with core losses in coils. Calculations are omitted for (23) for the same reasons given for (16).

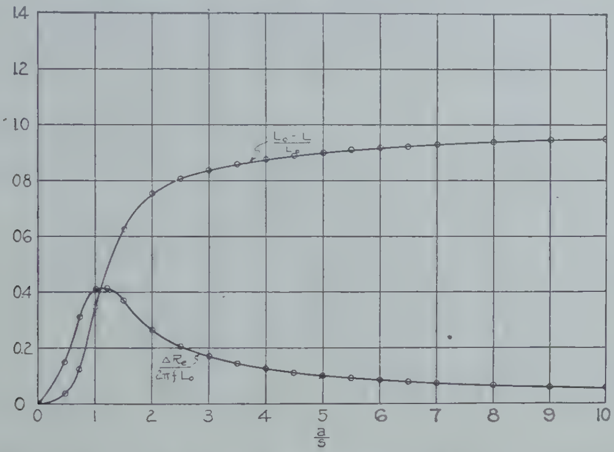

Fig. 4—Theoretical curves showing the variation of inductance, L, and eddy-current component of effective resistance, ΔR_e, of iron-cored coils with frequency, permeability, and conductivity.

TABLE I
THEORETICAL CURVES
Fig. 4

$\frac{a}{s}$	$\frac{L}{L_0}$	$\frac{\Delta R_e}{2\pi f L_0}$	$\frac{L_0 - L}{L_0}$
0	1.00	0	0
0.50	0.965	0.160	0.035
0.75	0.861	0.311	0.139
1.00	0.676	0.405	0.324
1.178	—	0.414	—
1.25	0.499	0.410	0.501
1.50	0.373	0.366	0.627
2.00	0.249	0.263	0.751
2.50	0.197	0.202	0.803
3.00	0.166	0.166	0.834
3.50	0.143	0.143	0.857
4.00	0.125	0.125	0.875
4.50	0.111	0.111	0.889
5.00	0.100	0.100	0.900
5.50	0.091	0.091	0.909
6.00	0.083	0.083	0.917
6.50	0.077	0.077	0.923
7.00	0.071	0.071	0.929
8.00	0.062	0.062	0.938
9.00	0.055	0.055	0.945
10.00	0.050	0.050	0.950

TABLE II
CORE DATA

Coil No.	Material	Thickness of laminations inches	Resistivity microhms per cm³	Permeability max/cm²/gil/cm	Total cross-sectional area cm²
1	78-½ Permalloy	0.0136	17.73	5900	0.785
2	45% Permalloy	0.0148	55.33	1940	0.815
3	3.8% Chrome Permalloy	0.0650	69.00	16500	0.787
4	Silicon steel	0.0145	57.13	552	0.834

Example of the Use of Fig. 4

As an illustration of the use of the curves in Fig. 4, suppose we have a coil wound upon a silicon steel core composed of laminations 0.014 in. in thickness. Assuming a conductivity of 1.61 10^4 ohms per cm^3, and a permeability of 700 maxwells per cm^2 per gilbert per cm, we find the skin thickness to be

$$s = \frac{5030}{\sqrt{1000.700.16100}} = 0.0473 \text{ cm at 1000 cycles, and} \quad (25)$$

$$s = \frac{5030}{\sqrt{8000.700.16100}} = 0.0167 \text{ cm at 8000 cycles.} \quad (26)$$

We have $a = 2.54 \times 0.014 = 0.01778$ cm, whence

$$\frac{a}{s} = 0.376 \text{ at 1000 cycles and} \quad (27)$$

$$\frac{a}{s} = 1.063 \text{ at 8000 cycles.} \quad (28)$$

From Fig. 4, corresponding values of $(L_0 - L)/L_0$ are 0.015 at 1000 cycles, a 1½ per cent decrease in inductance, and 0.37 at 8000 cycles, a 37 per cent decrease in inductance, due to eddy current shielding.

Had one of the nickel-iron alloys having an initial permeability of 7000 been assumed, the values of $(L_0 - L)/L_0$ would have been 0.54 and 0.867, corresponding to 54 per cent and 86.7 per cent decreases in inductance, respectively.

If the inductance in the first case had been 0.5h at zero frequency, the inductance at 8000 cycles would be 0.315h and the inductive reactance would amount to 15,820 ohms. From Fig. 4, the corresponding value of $\Delta Re/2\pi f L_0$ is 0.419, whence the eddy current component of the effective resistance of the coil would equal 6630 ohms. This times the square of the current through the coil would equal the power loss in the coil due to eddy currents in the core.

Experimental Data

In order to test the correctness of the assumptions upon which the foregoing theoretical discussion is based, the variation of inductance with frequency was measured for several toroidal coils having cores made up of rings of sheet material, the separate laminations being insulated thoroughly from one another by paper separators. The measurements were made at very low values of induction, in order to insure that the permeability of the core materials should not vary

appreciably during the test. The core materials chosen presented a wide range in values of resistivity and permeability as shown in Table II. The number of turns in each coil was so small as to preclude any possibility of masking the true shielding effects by spurious inductance readings due to distributed capacitance in the windings.

The value of initial permeability given for each of the cores was determined ballistically after very careful demagnetization of the sample. The values of resistivity and thickness of the cores were

TABLE III
COIL DATA
Fig. 5

Coil No. 1 78-½ Per Cent Permalloy				Coil No. 2 45 Per Cent Permalloy			
f cycles per sec.	$\frac{L_{obs.}}{\mu h}$	$\frac{a}{s}$ calc.	$\frac{L_0-L}{L_0}$ obs.	f cycles per sec.	$\frac{L_{obs.}}{\mu h}$	$\frac{a}{s}$ calc.	$\frac{L_0-L}{L_0}$ obs.
0	1670	0	0	0	570	0	0
500	700	1.40	0.581	500	555	0.494	0.027
1000	386	1.97	0.769	1000	520	0.698	0.089
2000	242	2.80	0.855	2000	420	0.990	0.264
3000	187	3.42	0.888	3000	333	1.212	0.416
4000	156	3.96	0.9066	4000	275	1.400	0.518
5000	131	4.43	0.9215	5000	226	1.565	0.604
6000	117	4.85	0.9300	6000	195	1.712	0.658
7000	105	5.23	0.9371	7000	172	1.850	0.698
8000	95	5.60	0.9431	8000	156	1.982	0.726
9000	88	5.95	0.9474	9000	144	2.100	0.748
10000	80	6.95	0.9521	10000	135	2.210	0.763

Coil No. 3 3.8 Per Cent Chrome Permalloy				Coil No. 4 Silicon Steel			
f cycles per sec.	$\frac{L_{obs.}}{\mu h}$	$\frac{a}{s}$ calc.	$\frac{L_0-L}{L_0}$ obs.	f cycles per sec.	$\frac{L_{obs.}}{\mu h}$	$\frac{a}{s}$ calc.	$\frac{L_0-L}{L_0}$ obs.
0	4675	0	0	0	1840	0	0
500	235	5.63	0.950	500	1838	0.252	0.002
1000	168	7.98	0.964	1000	1820	0.357	0.010
2000	100	11.27	0.979	2000	1750	0.506	0.049
3000	77	13.80	0.984	3000	1680	0.620	0.087
5000	57	17.83	0.988	5000	1560	0.800	0.151
8000	42	22.50	0.989	8000	1300	1.001	0.294
10000	37	25.20	0.992	10000	1125	1.132	0.389
				15000	836	1.390	0.546
				20000	660	1.600	0.642
				30000	455	1.960	0.753
				40000	365	2.265	0.802
				50000	305	2.525	0.834

determined by measurements made upon the individual laminations. The data in some instances were rechecked and a perfect agreement with the original observations was obtained.

In spite of these precautions, the observations as plotted in Fig. 5 disagree with the predicted values to an extent which may warrant the assumption that some phenomenon in addition to eddy current shielding is causing the inductance to decrease with frequency. As will be

noted from (22), for values of a/s greater than 2, $L/L_0 = S/2a$ to less than 0.01 per cent, so for all values of f above a certain limit, L_0/L plotted against $2a/s$, or $1/L$ plotted against $\sqrt{f}$, should be a straight line through the origin. This affords a very simple means of testing

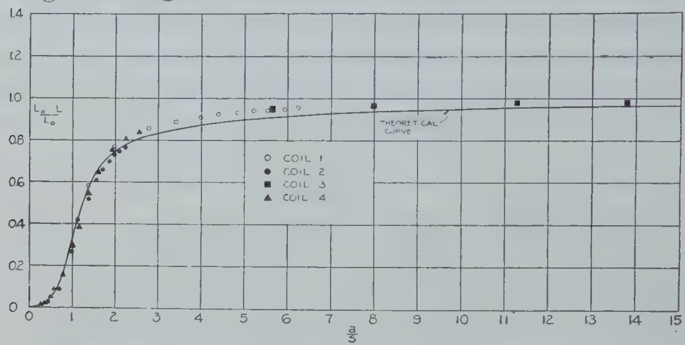

Fig. 5—Graph showing the agreement of observed values of $(L_0 - L)/L_0$ vs a/s, with the theoretical curve, which is shown as a full line.

whether the observed discrepancies between theory and measurements were due to faulty assumptions as to the parameters μ, γ, t, etc., or

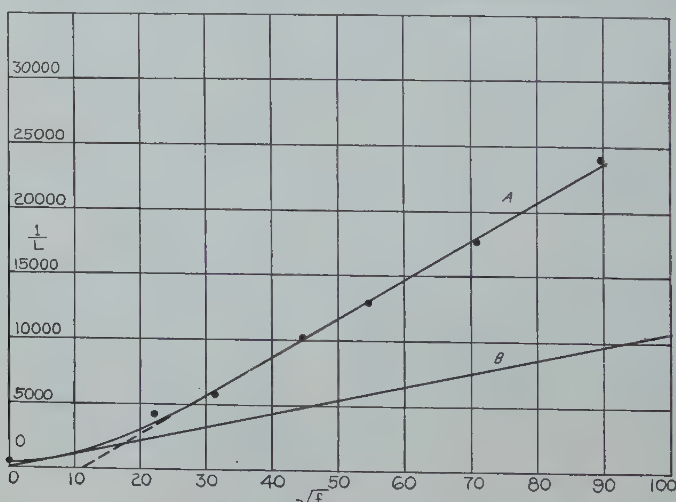

Fig. 6—The plotted points of curve A show values of $1/L$ vs $\sqrt{f}$ for coil No. 3. Below is shown at curve B, the calculated straight line on which the plotted points should lie for values of f greater than 500.

whether a different law is followed. Trial shows, however, that observed values of $1/L$ vs $\sqrt{f}$ do not give a straight line through the origin, hence the suspicion that some phenomenon other than eddy current shielding is also involved (see Fig. 6). What this phenomenon is, whether it is some sort of molecular magnetic lag or viscosity, is

TABLE IV
COIL No. 3
Fig. 6

f cycles per sec.	L μh	$\sqrt{f}$	$1/L$ obs.	$1/L$ calc.
0	4675	0	224	—
500	235	22.3	4250	2405
1000	168	31.6	5950	3410
2000	100	44.7	10000	4820
3000	77	54.8	13000	5910
5000	57	70.7	17550	7620
8000	42	89.5	23800	9650
10000	37	100.0	27000	10800

not apparent. The indications are, at least, that the decrease of inductance of iron-cored coils will generally be greater than that indicated by the theoretical curves herewith presented, particularly for values of a/s greater than 2. It is the writer's belief that the portion of the total decrease in inductance actually due to eddy current shielding is correctly given by the curve of Fig. 4.

Appendix

Mathematical Derivation of Differential Equation

$$\frac{d^2B}{dx^2}+\frac{1}{x}\,\frac{dB}{dx}-jc^2B=0.$$

Inasmuch as the writer is unable to furnish a reference giving a straightforward derivation of equation (1), the method of deriving it is set forth as follows:

In the case of the round magnetic core consider an elementary cylindrical shell of the core material, of unit length, radius x, and thickness dx. The axis of the shell is taken to coincide with the axis of the core. The alternating magnetic flux, B, in the core will be parallel to its axis and will induce an e.m.f., E, in the shell, perpendicular to its length and radius vector. As a result, eddy currents of density I will flow in the shell. The equations connecting B, E, and I serve as a basis for deriving (1).

The conductance of the elementary cylindrical shell to the eddy currents is $\gamma dx/2\pi x$ and the total current in the shell is $I\,dx$, whence we have

$$I=\frac{\gamma}{2\pi x}E. \tag{1a}$$

The total flux in the shell is $2\pi xBdx$ and the increment in voltage between the inner and outer surface of the shell is, vectorially,

$$dE=-j4\pi^2fBxdx\cdot 10^{-8}. \tag{2a}$$

The increment in magnetizing force between the inner and outer surfaces of the shell is $-4\pi/10\ I\ dx$ whence

$$dB = \mu dH = -\frac{4\pi}{10}\mu I dx. \tag{3a}$$

Eliminating E and I between (1a), (2a), and (3a), results in (1).

$$\frac{d^2B}{dx^2} + \frac{1}{x}\frac{dB}{dx} - j8\pi^2 f\gamma\mu B\cdot 10^{-9} = 0 \quad \text{or}$$

$$\frac{d^2B}{dx^2} + \frac{1}{x}\frac{dB}{dx} - jc^2B = 0. \tag{1}$$

The complete solution of this equation[3] is

$$B_x = C_1 J_0(\sqrt{-j}\,cx) + C_2 K_0(\sqrt{-j}\,cx)$$

B_x must everywhere be finite and since

$$K_0(z) = -\alpha \text{ at } z = 0, \quad C_2 \equiv 0.$$

Next, since $B_x = B_s$ at $x = \alpha$, we have $B_s = C_1 J_0(\sqrt{-j}\ ca)$

whence $$C_1 = \frac{B_s}{J_0(\sqrt{-j}\,ca)}$$

and finally

$$B_x = B_s\frac{J_0(\sqrt{-j}\,ca)}{J_0(\sqrt{-j}\,ca)}. \tag{3}$$

Equation (2) for the flat sheet core is arrived at by a similar process.

[3] Byerly, "Fourier Series and Spherical Harmonics".

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BOOK REVIEWS

Principles of Radio, by KEITH HENNEY. John Wiley and Sons, Inc., New York. 464 pages. Price $3.50.

Contents: Fundamentals of electrical physics and engineering; properties of alternating-current circuits and circuit elements; the vacuum tube; amplifiers and detectors; receiving systems; vacuum tube power supply; oscillators and transmitters; antennas and wave propagation.

In spite of the overproduction of textbooks of radio during the past few years, Henney's *Principles of Radio* may be unreservedly recommended for inclusion in every radio engineer's library. The author has a grasp of both the theoretical and practical aspects of the subject which, while not unique, is certainly unusual among writers of textbooks. In this case he has merged the two viewpoints into a single adequate treatment.

Mathematics is employed to the extent required for clear, and not too lengthy, explanations. While there has been no attempt to get down to the boy-electrician level, the book can be readily understood by anyone with high school training in mathematics and physics. There is ample preliminary material on such subjects as bridges, electrolysis, electromagnetism, inductance, transformer circuits, etc., to make the later discussions comprehensible. Graphs and vector diagrams are extensively used.

Henney thinks clearly and does not resort to conventional methods of avoiding thought, either on his part or that of the reader. The text is well arranged, but where clarity is to be gained, the author often includes parenthetical explanations; there is no tendency to carry logic to a wasteful extreme. An index is provided and the inside cover pages have been utilized for the addition of useful tables.

CARL DREHER*

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A Critical Review of Literature on Amplifiers for Radio Reception. Radio Research Special Report No. 9. Published by His Majesty's Stationery Office, London. pp. VIII+239. 6 x 9½ cloth. Price 5 s. net.

This report contains a review and general bibliography of the more recent literature on the design of radio receivers. It has been prepared at the National Physical Laboratory on behalf of the Radio Research Board with the object of indicating the lines along which future research may be profitably undertaken. To bring out the relative importance of the different sections the review is essentially critical and all the papers cited have been examined with this point in view. The compilers believe that the bibliography is practically complete from 1916 to April, 1929, and some papers published prior to 1916 are noted.

The review is divided into four main sections: I. Radio Frequency Amplifiers; II. Rectification; III. Audio Frequency Amplifiers; IV. Measurements. Sections I, III, and IV have been compiled by H. A. Thomas, and section II by F. M. Colebrook.

The main sections of the review have been subdivided and each subdivision is followed by a critical essay in which the work done on a particular subject is

summarized and important questions upon which further research is needed are indicated. Each essay is followed by a bibliography with abstracts and critical comments of the compiler.

The review is preceded by a list of journals consulted and table of contents. It is followed by an author index.

This is an excellent guide to the study of the literature on electron tubes and their associated apparatus, especially that literature concerning the design of radio receivers.

S. S. KIRBY*

* Bureau of Standards, Washington, D.C.

Radio Telegraphy and Telephony, by RUDOLPH L. DUNCAN and CHARLES E. DREW. John Wiley and Sons, Inc., New York. 950 pp. 6 x 9; 468 illustrations. Price $7.50.

This book is a product of the School Division of the Radio Corporation of America. The authors do not make extravagant claims for it but expect that it may not only be of instructional value to nontechnical students and readers generally, but that it may also serve the radio field as a practical handbook. Their expectations are well realized. The first 191 pages are an elementary treatment of the principles of electricity and magnetism, motors, generators, and storage batteries. Pages 192 to 508 contain a discussion of vacuum tubes and radio receivers both a-c and d-c and their accessory apparatus, such as loudspeakers and rectifier devices. Chapters on high voltage condensers, antennas, and resonance follow. Pages 602 to 842 deal with transmitters and transmitter equipment, broadcast, telegraph, short wave, spark, and arc. There is also a chapter on direction finders and an appendix of useful information. There are a few scattered inaccurate statements. Principles, methods, and commercial equipment are described in minute detail. Much practical, usable data covering the radio field has been collected in this book.

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BOOKLETS, CATALOGS, AND PAMPHLETS RECEIVED

Copies of the publications listed on this page may be obtained gratis by addressing a request to the manufacturer or publisher.

Data Sheet No. 7 describes the Pilot superwasp high-frequency receiver for operation from direct current, while the superwasp for alternating-current operation is described in data sheet No. 115 of the Pilot Radio and Tube Co., Lawrence, Mass.

The Sensitive Research Instrument Corp. of 142 East 32nd St., New York City, has recently published a folder describing their d-c Poly-Ranger and their a-c Poly-Ranger. Both instruments have thirteen ranges selected by a rotary switch. The instrument for alternating current is a thermocouple type, and may be used on frequencies as high as 3000 cycles.

Several data sheets describing the amperite self-adjusting line controls for a-c operated radio receivers are available for distribution, from the Amperite Corp., 561 Broadway, New York City.

Bulletin No. 195, issued by Herman H. Sticht & Co., 15 Park Row, New York City, is a 12-page booklet describing the Paragon Megohmer, made by Siemens and Halske. The Paragon Megohmer is a self-contained, portable instrument for measuring insulation and other high resistances, from 0–10 megohms to 8–10,000 megohms.

Several pieces of descriptive literature on recent Weston developments are available from the Weston Electrical Instrument Corp., of Newark, N. J. . A four-page folder describes their Model 565 radio set tester and tube checker. This model supplements the Model 547 set tester and contains several improvements not found in the older model. In the newer tester the ranges of the instruments have been extended and a modulated radio-frequency oscillator is incorporated.

A counter tube checker which is inteded for use by radio dealers to indicate relative values of mutual conductance is described in a data sheet and is known as Model 555.

Model 564 voltohmeter, having voltage ranges of 3, 30, 300, and 600 volts, and resistance ranges of 10,000 and 100,000 ohms is described in a data sheet.

The Weston resistance meter, reading 0–3 volts and 0–10,000 ohms uses the Model 506 2-inch flush mounting movement. The resistance meter is described in a separate sheet. A portable d-c instrument reading 0–8 volts, 0–200 volts, and 0–2 milliamperes, is described in a single data sheet. The instrument is intended to service automobile radio receivers, and bears the catalog designation Model 489.

A four-page folder entitled "Weston Radio Instruments" lists a number of popular 2-inch and 3-inch instruments for radio purposes. Instruments for measuring direct current, alternating current, and radio-frequency currents are described. A volt-milliammeter for servicing automobile radio receivers and a double range d-c milliammeter are among the newer developments shown.

Booklet No. IV, published by the Cambridge Instrument Co., 3512 Grand Central Terminal, New York City, is a 70-page booklet giving brief descriptions of electrical instruments for a-c measurements, at commercial, audio or radio frequencies.

List No. 918 of the Cambridge Instrument Co., describes a three-element Duddell oscillograph for voltages up to 600. Oscillographs are made for voltages up to 100,000.

The Campbell frequency meter, for measuring frequencies between 180 and 4,000 cycles by the null method is described in List No. 170 issued by the Cambridge Instrument Co.

REFERENCE TO CURRENT RADIO LITERATURE

THIS is a monthly list of references prepared by the Bureau of Standards and is intended to cover the more important papers of interest to the professional radio engineer which have recently appeared in periodicals, books, etc. The number at the left of each reference classifies the reference by subject, in accordance with the scheme presented in "A Decimal Classification of Radio Subjects—An Extension of the Dewey System," Bureau of Standards Circular No. 138, a copy of which may be obtained for 10 cents from the Superintendent of Documents, Government Printing Office, Washington, D.C. The various articles listed below are not obtainable from the Government. The various periodicals can be secured from their publishers and can be consulted at large public libraries.

Note.—Beginning with this issue the classification numbers are on the revised system published in the August issue. These numbers differ slightly in some cases from those used previously.

R000. Radio Communication

R030 Grinsted, W. H. Units used in telephone transmission engineering. *Experimental Wireless & W. Engr.* (London), **7**, 439; August, 1930.

The bel, decibel, neper, and decineper are defined. The unit by which cross-talk is measured is discussed. A scale is reproduced giving the relationship between the units generally used in telephone engineering.

R100. Radio Principles

R113.61 Appleton, E. V. and Green, A. L. On some short wave equivalent-height measurements of the ionized regions of the upper atmosphere. *Proc. Royal Soc.* (London), **128**, 159–178; July 1, 1930.

The results of a series of measurements by the frequency change method of the equivalent heights of the ionized regions in the upper atmosphere are described and discussed. Measurements were made using 100-meter waves emitted at Teddington and received and recorded at London, Cambridge, and Peterborough. Evidence showing the existence of two deflecting regions was obtained, the equivalent heights of which were about 100 km and 230 km during the daytime. The lower region was found to reflect only in the daytime and usually only in the middle of the day. Agreement in the heights measured at the three stations was obtained by certain simple assumptions as to the nature of the interference causing the signal maxima and minima. The equivalent height of the Kennelly-Heaviside layer in the early morning is shown to be greater for 100-meter waves than for 400-meter waves.

R113.61 Appleton, E. V. and Ratcliffe, J. A. Some simultaneous observations on downcoming wireless waves. *Proc. Royal Soc.* (London), **128**, 133–158; July 1, 1930.

Simultaneous measurements by the frequency change method of the equivalent height and reflection coefficient of the ionized layer for 400-meter waves have been made at different distances from a wireless transmitting station. The equivalent height was found not to vary markedly with the distance between the transmitter and receiver. Additional evidence of nighttime penetration of the Kennelly-Heaviside layer has been found. On such occasions reflection has taken place from a still higher ionized region. The reformation of the lower layer is observed practically simultaneously at different receiving stations. The lack of marked variation of the reflection coefficient of the layer with angle of incidence is interpreted as indicating the existence of an absorbing zone situated at a lower level in the atmosphere than the region responsible for the deviation of the waves.

R113.62 Störmer, C. Do wireless echoes of long delay come from space outside the moon's orbit? (Address). *Proc. Royal Soc.* (Edinburgh), **50**, 187–199; Sessions, 1929–1930.

A narrative account is given of the experiments in which wireless echoes of long delay were heard and timed. The theory that these echoes are reflections from unstable streams of electrons coming from the sun, traversing disruptedly the space outside the moon's orbit, and causing aurora when they come down to the earth is outlined. Verifications of predictions based on the theory have occurred and are noted.

R113.7×R270 Cherry, R. O. Field intensity measurements around some Australian broadcast stations. *Proc. Physical Soc.* (London), **42**, 192–211; April 15, 1930.

The field intensities of transmitting stations have been measured in order to determine some of the factors controlling the propagation of radio waves. A description is given of the apparatus employed and the method of measurement. From field strength contours of three broadcast stations it is concluded: (1) that very rapid attenuation of the signal is caused by forest areas; (2) that the effective conductivity of the various types of ground surface met with varies from 4×10^{-13} to 0.07×10^{-13} e.m.u.; (3) that the use of longer waves gives marked increase of intensity at distant points beyond forest areas; (4) that Sommerfeld's formula is correct for daylight transmission over sea water up to a distance of 85 miles; and (5) that the efficiency of radiation of the three antennas examined ranges from 48 to 60 per cent. The limits of signal intensity required for satisfactory reception are discussed and it is suggested that atmospheric and other disturbances are less prevalent in Australia than in Europe and America.

R113.7 Stoye, K. Eigenschaften von ultrakurzen Wellen. (Properties of ultra-short waves). *Zeits. für Hochfrequenztechnik*, **35**, 235–236; June, 1930.

An account is given of communication experiments with 3.4-meter, 5-meter, and 6.8-meter waves. A direct optical path between transmitter and receiver was found to be necessary for communication with 3.4-meter waves, but with the 5-meter and 6.8-meter waves signals could be heard in valleys and cellars out of the direct line of sight from the transmitter.

R143 Reed, M. Electrical wave filters. (Concluded from p. 386, July issue). *Experimental Wireless & W. Engr.* (London), **7**, 440–445; August, 1930.

Composite wave filters are discussed. It is shown that these can be built up from sections which are derived from the same simple filter and that these sections can be so selected as to give any required attenuation characteristic and terminal impedance. To illustrate the advantages of the composite filter, the design of a low-pass filter and of a band-pass filter is considered. Transmission losses in filters due to incorrect terminations are treated. The necessary conditions for the reduction of these losses to a minimum are pointed out.

R146.1 Bunimowitsch, W. Ueber Frequenzverdopplung mit Elektronenröhren. (On frequency doubling with electron tubes). *Zeits. für Hochfrequenztechnik*, **35**, 223–231; June, 1930.

A combination graphical and algebraic method is developed for treating frequency doubling in vacuum tube circuits. The tube characteristics and the limits of stability of the various parameters are used as the basis of calculations. The formulas developed are applied to an experimental case.

R148. Heilmann, A. Einige Betrachtungen zum Problem der Frequenzmodulation. (A treatment of the problem of frequency modulation). *Elek. Nach. Technik*, **7**, 217–225; June, 1930.

The problem of frequency modulation is treated from the mathematical viewpoint, and the theoretical results are supplemented by a consideration of the behavior of typical modulation circuits. Conclusions are rendered more intelligible and applicable by expressing them graphically, particularly in the cases of single side-band symmetrical and unsymmetrical modulation.

R148.1×R140 Baggally, W. On banks of paralleled valves feeding reactive loads without distorting the wave-form. *Experimental Wireless & W. Engr.* (London), **7**, 430–438; August, 1930.

A method of solving problems involving a bank of vacuum tubes in parallel feeding an impedance load is given. It is shown that with inductive loud-speakers it is not possible to operate the bank under optimum power conditions with linear input because distortion sets in at the lower frequencies. A method of obviating the distortion is given.

R 200. Radio Measurement and Standardization

R214 Lucas, H. J. Some developments of the piezo-electric crystal as a frequency standard. *Jour. Institution Elec. Engrs.* (London), **68**, 855–872; July, 1930.

Some observed errors in quartz piezo-electric resonators employed as frequency standards are shown to be due to frictional loading and losses arising from atmospheric humidity. Methods adopted to eliminate these are described. The use of the improved quartz crystal as a control element in a vacuum tube maintained source of oscillations is treated. The frequency stability of such a system is investigated. The errors are found to be largely due to the vacuum tube system, and methods designed to eliminate these are discussed. A complete calibration equipment consisting of a multivibrator system with a range of 1–6000 kc per sec. in steps of 1 kc per sec. centrally controlled by a quartz crystal is shown.

R214 Marrison, W. A. The crystal clock. *Proc. National Acad. Sciences*, **16**, 496–507; July, 1930.

A crystal clock designed especially as a reference standard of frequency for the Bell System is described. It consists essentially of a generator of constant frequency controlled by a resonator of quartz crystal, with suitable means of producing controlled, continuous rotations to operate time indicating and related mechanisms. The electrical and mechanical details of the apparatus are briefly given, and performance data are reproduced indicating the constancy of the rate of the clock. A number of its inherent advantages over other timekeeping devices are pointed out and certain special applications of the apparatus are noted.

R251 Schäffer, W. Definition der Leistung von Telefoniesendern. (Definition of the power of a telephone transmitter). *Zeits. für Hochfrequenztechnik*, **35**, 232–235; June, 1930.

The question of determining the power rating of a radiotelephone transmitter is discussed on the basis of the definition adopted at the Hague Conference by the C.C.I.R. in 1929. Methods are given for measuring the radiation resistance of an antenna and the effective radiating antenna current.

R300. Radio Apparatus and Equipment

R355.5 Dennhardt, A. Ueber Mehrrohrschaltungen für sehr hohe Frequenzen. (On multitube circuits for producing very high frequencies). *Zeits. für Hochfrequenztechnik*, **35**, 212–223; June, 1930.

Multitube circuits for generating currents of very high frequency are discussed. By using a push-pull arrangement and by tuning the filament circuit an output power of three watts of frequency as high as 3.75×10^8 cycles per second ($\lambda = 80$ cm) has been attained. With such a transmitter telephone communication was successful over a distance of 12 km.

R365.2 Paul, R. W. Flat piston moving coil loud speakers. *Experimental Wireless & W. Engr.* (London), **7**, 421–429; August, 1930.

The development of a flat diaphragm moving coil loud-speaker is outlined. The design and construction of a Balsa wood diaphragm, the method of mounting it, and the design of the moving coil and magnet for use with it are described. Aural tests of the completed speaker and measurements of its performance are discussed. The response curves as experimentally measured and as calculated are reproduced.

R400. Radio Communication Systems

R412×R510 Wilson, W. and Espenschied, L. Radiotelephone service to ships at sea. *Bell Sys. Tech. Jour.*, **9**, 407–428; July, 1930.

The American end of the ship-to-shore telephone system and the connecting equipment on board the S.S. Leviathan are discussed. An outline is given of previous work in this field and of the technical problems involved in the use of short waves. The shore station facilities and the ship equipment developed for the

service are described. The results are given of the first trip of commercial service of the Leviathan.

R500. Applications of Radio

R526.1 Smith-Rose, R. L. The equisignal zone radio beacon and air navigation. *Nature* (London), **126**, 98–100; July 19, 1930.

An historical account is given of the equisignal zone radio beacon and its application as an aid to air navigation. The work of the U.S. Bureau of Standards in the development of this type of beacon, both aural and visual, is reviewed. The adoption of the equisignal zone beacon by the Airways Division of the Department of Commerce for use in marking the airways of the United States is noted.

R550 Gerth, F. and Hahnemann, W. Einige Betrachtungen zum Problem des Gleichwellenrundfunks. (A treatment of the problem of common frequency broadcasting). *Elek. Nach. Technik*, **7**, 226–231; June, 1930.

Both the synchronized and unsynchronized systems of simultaneous, common frequency broadcasting are considered with regard to the relative merits of each as to frequency distortion, phase distortion, and fading.

R554
×621.385.91 Clark, A. B. and Green, C. W. Long distance cable circuit for program transmission. *Bell Sys. Tech. Jour.*, **9**, 567–594; July, 1930.

A system whereby the telephone cable network of the country may be utilized to transmit programs for broadcast stations over distances upward of 2000 miles has recently been developed and given a trial on a looped-back circuit 2200 miles long with very satisfactory results. It transmits ranges of frequency and volume somewhat in excess of those now handled by the open wire circuits which are used for program work and also in excess of those handled by present day broadcast systems when no long distance lines are involved. Transmission requirements of broadcast systems are dealt with and a description is given of the new cable system.

R800. Nonradio Subjects

621.375.1 Fischer, W. and Pungs, L. Beeinflussung von Schaltvorgängen durch Elektronenröhren. (The relay action of electron tubes). *Zeits. für Hochfrequenztechnik*, **35**, 205–212; June, 1930.

The efficiency of vacuum tubes when used in switching and circuit-breaking circuits is considered. Their capacity and time of action are compared with those of other relay systems. Data and oscillograms are given to show their behavior as a function of the grid bias and other circuit constants.

621.388 Ives, H. E., Gray, F., Baldwin, M. W. Image transmission system for two-way television. *Bell Sys. Tech. Jour.*, **9**, 448–469; July, 1930.

A two-way television system in combination with a telephone circuit has been developed and demonstrated. With this system two people can both see and talk to each other. Two television systems are employed. Scanning is by the beam method using disks containing 72 holes. Blue light is used for scanning and water-cooled neon lamps are employed to give an image bright enough to be seen without interference from the scanning beam. A frequency band of 40,000 cycles width is required for each circuit. Synchronization is effected by transmission of a 1275-cycle alternating current controlling special synchronous motors.

621.388 Slotter, H. M. Synchronization system for two-way television *Bell Sys. Tech. Jour.*, **9**, 470–477; July, 1930.

The development is described of a new control circuit which is in use in the new two-way television system between the Bell Telephone Laboratories at 463 West St. and the American Telephone and Telegraph Company Building at 195 Broadway, New York City.

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